R E Doherty

Electrical Engineering

February
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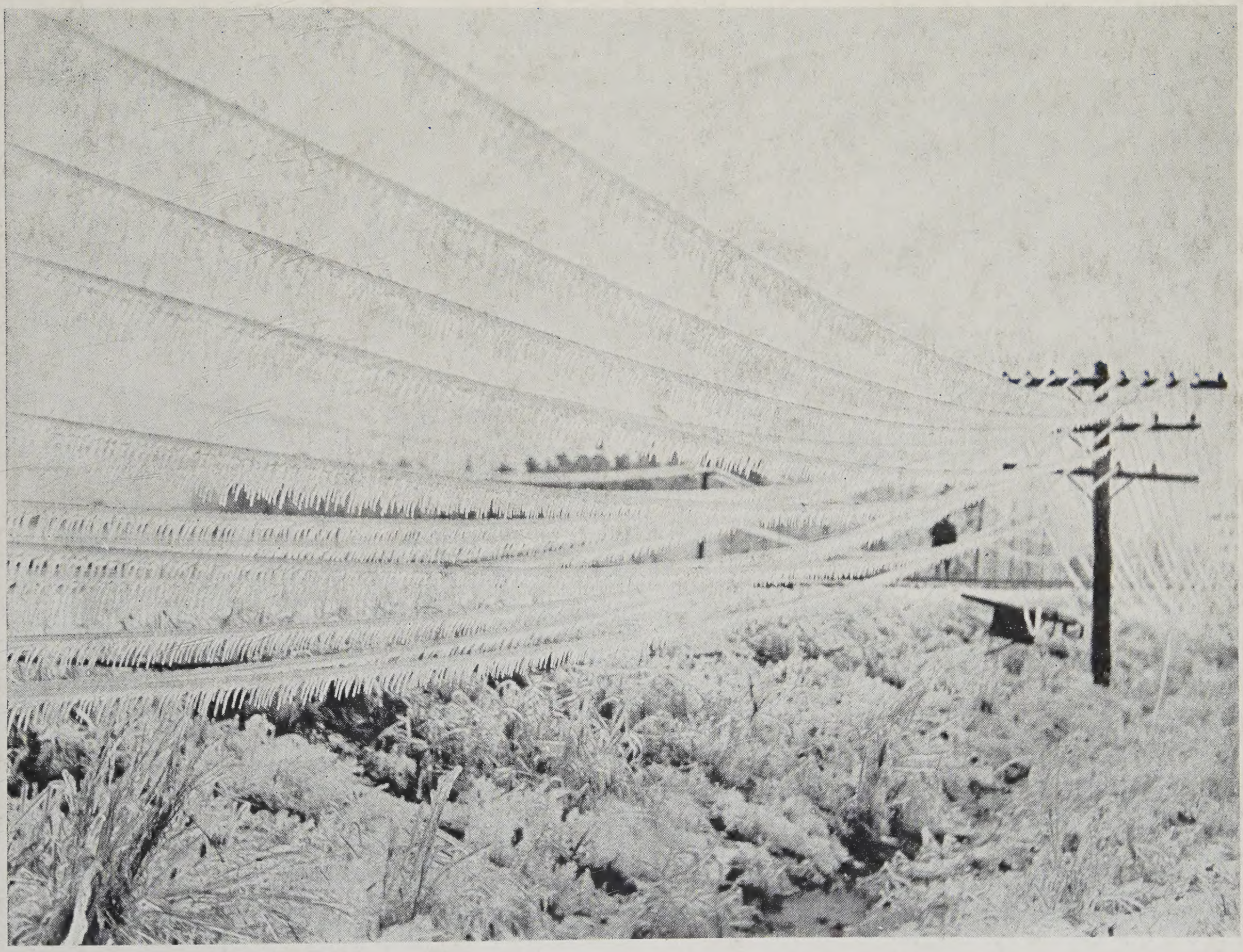

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A communication line "after the storm"
Photo courtesy W. R. Pollard, Georgia Power Co.

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The A.I.E.E. as an Educational Institution

By J. Allen Johnson, President A.I.E.E.

One of the objects of the A.I.E.E. as stipulated in its Constitution is "the maintenance of a high professional standing among its members." To maintain a high individual professional standing, an engineer must keep himself informed of technical advances in his field; in other words, if he expects to advance in his profession his education cannot stop after graduation from an educational institution, but must continue throughout his career. In this, his opening address at the Institute's 1935 winter convention, President Johnson brings clearly and forcefully to the attention of Institute members the many educational activities of the Institute that will help them maintain high professional standing. He urges that members of the Institute "realize the dependence of their individual professional standing upon their continuing education, and make full use of the opportunities offered by the Institute." This address was prepared originally for presentation at a meeting of the Pittsburgh Section of the Institute, and was read before that body by E. C. Stone on January 8, 1935; by request, President Johnson revised and extended it for presentation at the winter convention.

THE OBJECTS of the Institute, as defined by its Constitution, are (1) "the advancement of the theory and practice of electrical engineering and of the allied arts and sciences," and (2) "the maintenance of a high professional standing among its members." Now I think no one can misunderstand what is meant by the first of these 2 objects because advancement of the art by which we electrical engineers make our living has been so rapid and spectacular during the last half century that every one knows all about it; but that statement about maintaining "a high professional standing," just what does it mean? What is "professional standing" anyhow and what is involved in maintaining it high among our members?

The stumbling block to a clear understanding of all that this expression means is found in the word "professional"; and the reason, I think, lies in the fact that this word connotes so many different ideas, the combination of all of which is necessary to define it completely, that our inability simultaneously to remember and visualize them all leaves us in a state of mental confusion. In other words, we have only a foggy notion of what this second object of the Institute is.

Now what the term "profession" implies in all its connotations has been beautifully and completely stated by Doctor Wickenden in that inspiring address he delivered at the Institute's summer convention last year, which was published in the August 1934 issue of Electrical Engineering, page 1146. I cannot add anything to that statement. It is perfect as it stands; but I can and do urge every member to read it if he has not done so already. However, perhaps I can paraphrase the 2 objects of the Institute into such simple language that any one can understand them. It seems to me that these 2 clauses mean simply this, that the 2 objects of this Institute are:

1. To promote better electrical engineering.
2. To make better electrical engineers.

It is true that the language used in the constitution does not say anything about "betterment" of the professional standing of our members—it says "maintenance"; but whatever "professional standing" may mean in its entirety, in its technological and educational connotations its "maintenance" certainly implies at least a constant relationship between the individual engineer's knowledge of the art and the art itself. Since the Institute, by virtue of its first objective, is committed to the promotion of the advancement of the art, likewise, by virtue of its second objective, it must address itself to the task of helping its members to keep pace with the advancing art. Thus the Institute, in carrying out the second of its constitutional objectives becomes *per se* an educational institution, which brings me finally around to my subject.

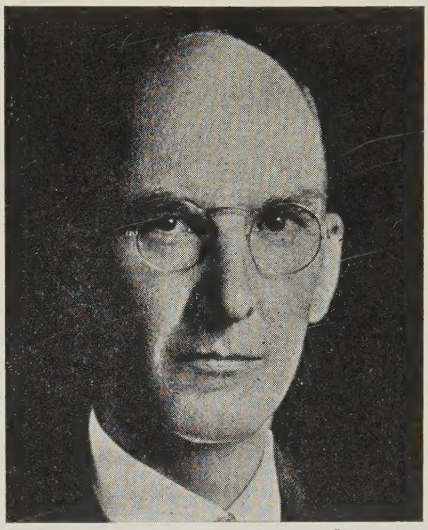
Maintaining a High Professional Standing

As pointed out so clearly by Doctor Wickenden in his address already referred to, a profession has group aspects as well as individual aspects. The standing of the profession as a whole is doubtless a group consideration, but the professional standing of an individual engineer is his own personal and individual affair. Once he has graduated from college and entered professional life his professional standing and its maintenance are up to him. The idea that graduation completes his education, and that all he thereafter has to do is to settle down and take it easy, is far from fact. That might conceivably be so if the science and the art were static, but in a field in which development occurs as rapidly as it has in that of electrical engineering, the college graduate quickly learns that he must continue his education even to *keep up* his professional standing; and if he expects to *advance* in his profession, which means broadening as well as deepening his knowledge, he must devote

a very considerable part of his time to study.

The fact that an engineer's professional standing is an individual matter seems to me to indicate conclusively that an engineer's relationship to his clients or employer also must be on an individual basis. To me this clearly implies that no man who deserves to be called an engineer could possibly even think of these relationships in terms of "collective bargaining." The whole idea of group or mass action in the relationships between engineers and their employers is, to my mind, repulsive to the whole concept of engineering as a profession. The kind of services that an engineer performs seem to me to be peculiarly individual services, the value of which depends upon the personality, characteristics, and abilities of the individual, one factor in which is his professional standing. One aspect of his professional standing is the degree in which he has kept up with the advance of his technology.

Here, it seems to me, is where the professional societies like the A.I.E.E. enter the picture. While it is true that every man's continuing education is his own responsibility, engineers discovered long ago that they could help each other educate themselves very effectively by forming societies through the medium of which discoveries and experiences might be interchanged and thus the progress of both engineering and engineers promoted. This motive was the principal one that prompted the organization of this Institute and that has dominated its development. It still is dominating its development, as will, I think, become clear if we now consider briefly the principal activities of the Institute in their educational aspects.



President Johnson

Educational Activities of the Institute

Papers and Discussions. Of course the main educational activity of the Institute is the publication, presentation, and discussion of papers. We are all more or less familiar with this activity, but I suspect that many of us do not think of it as an educational activity. Its success involves an immense amount of work for the "teachers" who write the papers, the committees that receive and review them, the technical program committee and the publication committee which together keep them moving through the mill, and the editorial staff which edits them and oversees the actual mechanics of their publication. Papers may be initiated either by individual members or by the technical committees. Formerly most papers were volunteered; but more recently it has become customary for the committees to sponsor coördinated groups of papers, often soliciting them from those who they feel to be best qualified to furnish the very latest information on a given subject. By this practice the educational value of the papers has been enhanced, as a result of the more orderly, coördinated, and comprehensive treatment of subjects.

I would like to say a word of appreciation of the work performed by the members of all these committees. To some extent, of course, this committee work furnishes its own compensation in the form of earliest contact with new developments in the art and in the inspiration of close personal contacts with other engineers engaged in similar work; but this fact does not detract in the least from the value of this work to the average Institute member. It is the faithful and devoted work of these men that makes the Institute possible and creates its value. I would like to say just a special word in appreciation of the work of the technical program committee under the chairmanship of Mr. R. N. Conwell, during the transition period between the old and the new publication policies. The problems involved in getting the new plan working smoothly, involving as it does the long time planning of convention programs and the supply of a steady stream of papers to the publication committee and the editorial staff in advance of and coördinated with their scheduled dates of presentation, have required no small degree of ingenuity, executive ability, forcefulness, and tact. I hope that sometime Mr. Conwell will tell us about it in Electrical Engineering, especially the mechanical device he has worked out for controlling the progress of papers through the mill.

Section, Branch, and District Activities. Besides providing a wider field for the discussion of Institute papers, these field activities also furnish opportunities for the presentation of lectures and demonstrations on electrical and allied subjects to the various local groups. These serve to broaden the educational work of the Institute thereby reaching many members who otherwise would not receive this benefit. The Branch activities give the young men in the colleges the benefit of the Institute's educational program to supplement that of the colleges, thus helping them to become better electrical engineers, to the benefit of both themselves and the profession as a whole. This contact with the embryo engineers also helps to bring home to them the necessity for continued educational effort after graduation, and thus reacts also to the benefit of the Institute.

Publication of Electrical Engineering. Under the new unified publication policy the Institute now places in the hands of every member and enrolled student all technical papers complete, related discussions, and also many special articles on subjects of current interest and importance written by recog-

nized authorities in their respective fields. Everything of a technical nature that is contributed by Institute members and adjudged by competent reviewers as worthy of publication, and much more besides, is there in ELECTRICAL ENGINEERING. Of course, no member is obliged to read this material, but if he does not he has no right to complain of its value or lack of value. I regret to have to say that I am afraid too many of our members fail to read ELECTRICAL ENGINEERING.

Committee on Education. Since a substantial part of our membership is made up of teachers of electrical engineering, the Institute would not be doing its full educational job if it did not provide thes men opportunities to discuss with each other the general subject of engineering education and to listen to the views of other engineers on the same subject. The Institute thus becomes not only a teacher of electrical engineering, but also a teacher of electrical engineering teaching. The work of this committee thus becomes a doubly important part of the Institute's educational activities.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

Since the Institute's principal activity is education, it is continually seeking ways to improve its methods and extend the services by which it tries to enable its members to keep themselves abreast of the advancing art and thus maintain their "professional standing." In this connection there are certain services that probably can be performed better and more efficiently by joint action of the national engineering societies and others than by each one separately.

Considerations such as these—which of course are equally true of all the engineering societies—coupled with the movement for the licensing of engineers in the various states, led to the formation of Engineers' Council for Professional Development (E.C.P.D.). This organization is composed of representatives of 5 national engineering societies (civil, mechanical, mining, chemical, and electrical) the Society for the Promotion of Engineering Education (representing the engineering schools), and the National Council of State Boards of Engineering Examiners. Thus there are brought together into a single body the 3 groups primarily interested in the "professional standing" of engineers, namely: the schools which lay its foundations, the societies which build it up and try to maintain it, and the public which apparently believes it necessary to "check up" on it before allowing any one to call himself a "professional engineer."

E.C.P.D. is devoting itself to all phases of the professional advancement of engineers, both as individuals and as a group, inclusive of the educational and legal aspects of professional standing. Its program is broad and comprehensive and I cannot take time now to mention all its activities and plans, but will mention only those having to do with the educational aspects of professional development.

In the first place, E.C.P.D. has been set up by its sponsors as an agency for the accrediting of engineering schools. This means that through E.C.P.D. the process of determining whether or not a certain curriculum offered by a certain school is a satisfactory preparation for the conferring of the bachelor degree in science or engineering may be carried out once for all and not have to be done 28 (or ultimately perhaps 48) times. The Institute's board of directors have been giving intensive study for more than 2 months to E.C.P.D.'s proposed plan for accrediting engineering schools, and voted to sanction the plan at its meeting on January 21, 1935; the plan will go into immediate effect. This activity is under the direction of E.C.P.D.'s committee on engineering schools. E.C.P.D. has also a committee on student selection and guidance, which is working on plans for more rational selection of engineering students. It has still another, a committee on professional training, which is working on plans for the guidance of the self education of junior engineers after graduation from college. If you will look in your December 1934 and January 1935 issues of ELECTRICAL ENGINEERING (pages 1667 and 133, respectively) you will find lists of books recommended for reading by such junior engineers. This list has been compiled by this committee of E.C.P.D., and I have no doubt that many older members can profit by it too, if they are not too proud to read books recommended for juniors. Other lists are to follow from time to time. Perhaps here is the germ of an idea for our technical committees in their respective fields.

E.C.P.D. also is planning a program of accrediting for individual engineers, and in due course all these educational plans are intended to dovetail in with the accrediting plans; these developments are still in the formative stage and are not ready for announcement.

NEW EDUCATIONAL OPPORTUNITIES

My purpose in thus outlining these educational plans and accomplishments of E.C.P.D., which is a joint agency of this Institute and others, is to indicate that this Institute still is developing new methods of providing educational opportunities for its members in order to facilitate in every way it can the "maintenance of a high professional standing among its members." In my opinion the success of the Institute in the past has been the result of its close adherence to the constitutional objectives which I quoted in the beginning, and I believe its future success also will lie in following these objectives and ideals with singleness of purpose. The present urge for the interpretation of professional standing in the sense of "group prestige" is only a phase of the present fever for getting something for nothing. It will pass in due time and we shall rediscover that worth while things are acquired only by effort. In closing, I can only urge, therefore, that our members realize the dependence of their individual professional standing upon their continuing education, and make full use of the opportunities offered by the Institute. If they will do this I feel sure that all petty financial considerations will fade into insignificance in comparison with the value of Institute membership as a means of "maintaining a high professional standing" through continuing education and consequent advancement in competence as an engineer.

High Speed Motion Pictures

High speed motion pictures have been found to be extremely useful in studying the motions of various types of mechanisms, especially transient high speed motions. Modern electronic devices have contributed new methods of producing accurately controlled light flashes of extremely high intensity so that now pictures may be taken by reflected light at rates up to several thousands per second.

By
H. E. EDGERTON
MEMBER A.I.E.E.

Mass. Inst. of Tech., Cambridge

MANY USES for high speed motion pictures have been found in engineering as well as in other fields. Studies of mechanisms by means of high speed motion pictures often reveal unsuspected variations in velocity, acceleration, and deformation, which become paramount in importance as the mechanism is operated at high speed. Motion pictures of this type are taken with the camera driven at a rate greater than normal, and then are projected at the usual rate. The projected picture shows the motion of the subject slowed down by that ratio by which the camera was speeded up.

For periodic motions stroboscopic light provides a very satisfactory means of observing the manner of operation, and for this reason the stroboscope[1] as a measuring instrument has proved itself to be a valuable laboratory instrument. The stroboscope is of very limited use for studying transient or nonperiodic motions, because of the shortness of the entire sequence of events and the difficulty of synchronizing the flashes of light to correspond to the motion. Stroboscopic light of sufficient intensity and of a relatively high frequency of flash, however, makes possible a method of ultra-high speed photography which has tremendous utility for the analysis of complicated and difficult mechanical problems. Modern electronic devices have contributed new methods of increasing the intensity of the light and of accurately controlling the instant of flash to such an extent that motion pictures by means of reflected stroboscopic light are now a practical possibility up to speeds of several thousand pictures per second.

All high-speed motion-picture cameras operating at rates of speed in excess of 200 or 300 frames per second must be constructed so that they use continuously moving film, since the mechanical difficulties of starting and stopping the film for individual pictures so far have been insuperable. In general there are 2 main types of high-speed motion-picture cameras with continuously moving film, namely:

1. Those utilizing a moving optical system to keep the image in a stationary position with respect to the film during the time of exposure.
2. Those utilizing a source of stroboscopic light the flashes of which are sufficiently brief to give a sharp image on the moving film.

The first type of camera is especially useful in studying problems involving the evolution of bright light, such as occurs in the photo-flash lamp and in the burning of explosive mixtures; also it is useful in direct sunlight and other places where the light intensity is high. The high speed cameras of Jenkins,[2,3] Heape and Grylls,[4] Suhara,[5,6,7] Tuttle,[8] Thun,[9,10,11] Legg,[12] and others are examples of the first type, since each of them depends upon a moving optical system to stop effectively the relative motion of the image and the film.

The second type of high speed camera is considerably simpler from a mechanical standpoint, but it requires somewhat involved electrical circuits for producing the flashing light. Bull,[13,14] Seguin,[15] Cranz,[16] N.A.C.A.,[17,18] and possibly others have constructed high speed cameras that depend upon instantaneous flashes of light for exposing photographs upon continuously moving film. This paper describes a camera of this second type that has been constructed at the Massachusetts Institute of Technology. The main advantage of this type of camera over the first type is the extremely short exposure time, which usually is less than 1/1,000, and may be as small as 1/100,000 of the time interval between successive pictures. The exposure time for the moving-optical-system type of camera purposely is made as long as possible in order to get satisfactory exposures, and sometimes actually is made longer than the time interval between successive pictures by simultaneous overlapping of exposures, as described by Jenkins. The second type of camera is of no use in the study of subjects that emit light, or in places brilliantly illuminated by sunlight.

The particular improvements of the camera described in this paper over previous cameras of the same type are:

1. Circuits making it possible to control the instant of flash accurately so that the pictures are framed properly on the film for projection, or so that the interval of time between flashes is known or determined accurately.
2. Circuits making it possible to obtain sufficient light so that reflected-light photographs (in contrast to the usual silhouette type of pictures) may be taken.
3. Mechanical design of camera giving rapid acceleration and constant speed, for a long strip of film.

Sources of Stroboscopic Light and Control Circuits

Capacitor discharges into mercury arc lamps have proved[19,20] to furnish a very useful method of ob-

Full text of a paper recommended for publication by the A.I.E.E. committee on instruments and measurements. Manuscript submitted March 12, 1934; released for publication July 3, 1934.

1. For all numbered references see bibliography at end of paper.

taining stroboscopic light for photographic work. The light is actinic, the discharge time is short, the timing is susceptible to accurate control by means of pulse amplifiers, the construction of the tubes is relatively simple, and as many tubes may be connected in parallel as desired, since they all flash at the same instant. Figure 1 shows 2 banks of mercury arc stroboscope tubes with 4 lamps in each, the power supply equipment that furnishes the necessary direct-current for charging the capacitors and the high speed camera.

A wiring diagram of the apparatus in Fig. 1 is shown in Fig. 2. A 6-phase 10-kw rectifier unit supplies direct current at 1,000 volts to charge the capacitors. Resistors in series with each capacitor limit the flow of current to the lamps in case of "holdover," but still allow the capacitors to become charged effectively during the interval between flashes. The time constant of a circuit consisting of resistance and capacitance is equal to RC seconds, where R is expressed in ohms and C in farads. This factor is important, since it gives the time required to charge a capacitor from an uncharged condition to 63 per cent of the ultimate charge. The time constant of the discharge capacitor C_1 and the charging resistor R_1 in the diagram, Fig. 2, should not be more than $^1/_2$ of the interval of time between successive flashes in order to have the capacitors effectively charged. A choke coil in series with the resistors is used to increase the time allowed for deionization. Usually this choke is designed to have a large value of inductance on the first part of the charging surge, and a smaller value thereafter.

Power required by a bank of stroboscope lamps depends upon many factors, but mainly upon the number of lamps, the frequency of flash, the size of flashing capacitor, and the voltage to which the capacitor is charged. A method of calculating the power requirement for any particular equipment is as follows: The energy stored in a capacitance of C farads charged to E volts is $E^2C/2$ joules. It is well known that as much energy is lost in the charging resistor as is stored in the capacitor when it is allowed to become fully charged. Therefore the energy required for each flash is E^2C joules. The total energy per second (power) is equal to the product of E^2C, the number of flashes per second, and the number of lamps in parallel; hence

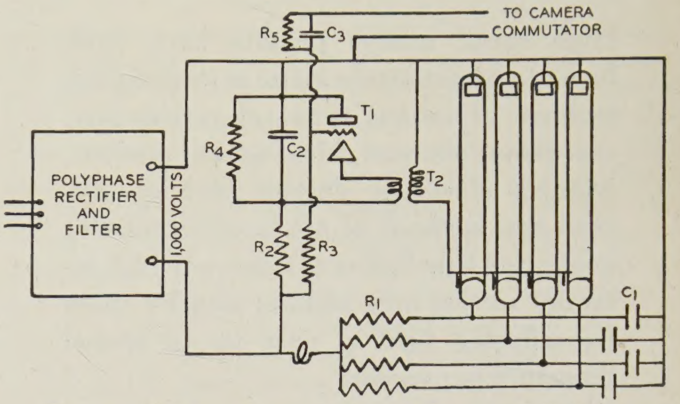


Fig. 2. Wiring diagram of a stroboscopic lighting source for taking high speed motion pictures

R_1	400 ohms, 180 watts	C_1	2 μf, 1,000 volts
R_2	1,400 ohms, 80 watts	C_2	1/8 μf, 1,000 volts
R_3	5,000 ohms, 10 watts	C_3	0.0001 μf, 5,000 volts
R_4	100,000 ohms, 20 watts	T_1	Grid-controlled mercury-vapor-filled tube
R_5	1 megohm, 2 watts	T_2	40:1 ratio transformer

Power in kilowatts required =

$$\frac{E^2C}{1{,}000}\left(\begin{array}{c}\text{number of flashes}\\\text{per second}\end{array}\right)\left(\begin{array}{c}\text{number of tubes}\\\text{in parallel}\end{array}\right)$$

As an example, 4 tubes with 2 μf across each, charged to 1,000 volts, and flashed at 600 pictures per second, require 4.8 kw. The filament heating losses and power required for the tripping circuit are not included and hence must be added. Each charging resistor would need to be 400 ohms or less for this case, in order for the time constant to be equal to or less than $^1/_2$ the time between flashes.

Experiments show that the required power is slightly larger than indicated by the equation when the stroboscope lamps are cold, and slightly smaller when the lamps are hot, although the light from the hot tubes may be a great many times brighter than from the cold ones. Studies by means of a cathode ray oscillograph show that the capacitor discharge through a cold lamp is oscillatory; and since the tube is a rectifier it leaves the capacitor with a reversed charge after the flash, thus requiring more energy to charge it for the next flash. As the temperature of the tube is raised, the tube absorbs a larger part of the energy, and therefore the oscillation is damped to a greater extent so that the capacitor does not accumulate as much charge of the reverse polarity. A hot tube actually will overdamp the oscillation and even prevent the capacitor from completely discharging.

A mercury arc lamp $^5/_8$ in. in diameter and 12 in. long is operated conveniently for short bursts at the

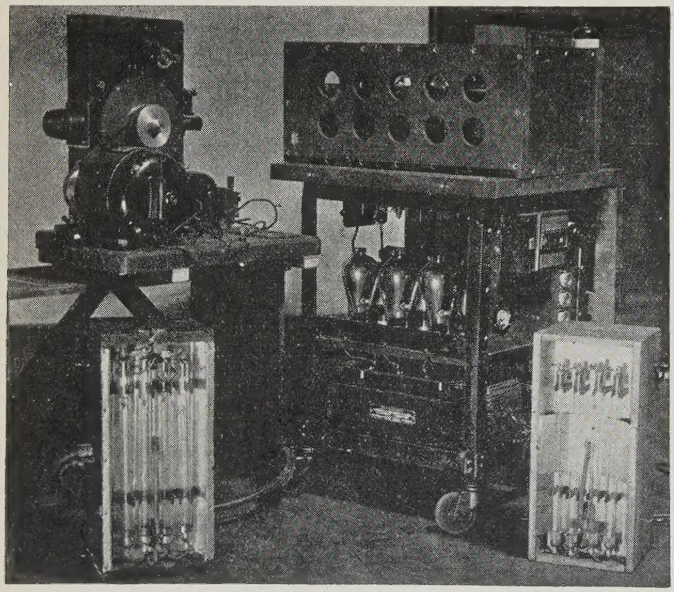


Fig. 1. High-speed motion-picture camera recently developed at Massachusetts Institute of Technology and the electrical apparatus for producing the stroboscopic light

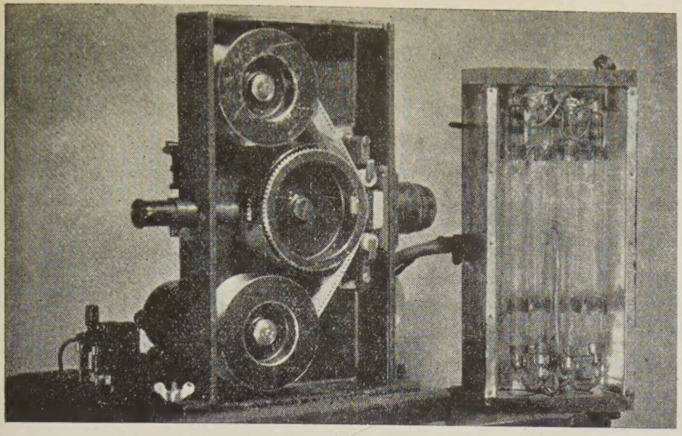


Fig. 3. High speed camera with cover off

value given in the preceding paragraph, that is, about 1 kw of power input. A period of 3 or 4 seconds of operation will warm up the tube, which increases the pressure of the mercury vapor, and as a result more light is obtained. Should the tube become too hot, an objectional trailer appears on the photograph, since the light lasts too long. The duration of the light in this case is greater because the apparent resistance of the mercury tube has been increased, which slows up the electrical time constant of the capacitor discharge.

The operation of the circuit is described briefly in the following paragraphs. The mercury arc stroboscope lamp needs to be well baked and operated at high temperature during exhaust, so that the vacuum is sufficiently good for the tube to withstand several thousand volts without breaking down. This is necessary so that capacitor C_1 in Fig. 2 may be charged to about 1,000 volts without a discharge occurring through the mercury arc lamp except at the desired instant. Control of the starting is obtained by the use of a pulse amplifier which is triggered by the commutator on the camera; the tube used in this amplifier is of the hot-cathode 3-element mercury-vapor-filled type (T_1 in Fig. 2). The firing must be controlled accurately and positively; otherwise the pictures will not be spaced uniformly on the film and will not be suitable for projection.

A high potential (10,000 to 30,000 volts), suddenly applied to a mercury-arc stroboscope tube on the outside of the glass just opposite the junction of the mercury and the glass, has the property of starting the tube and allowing the energy in capacitor C_1 to be discharged through it. Bright cathode spots are formed at the junction of the mercury and glass by the aid of the externally applied high potential, and these spots furnish emission to carry the large peak currents required for the quick capacitor discharges. The peak currents are in excess of 1,000 amp in the circuits used.

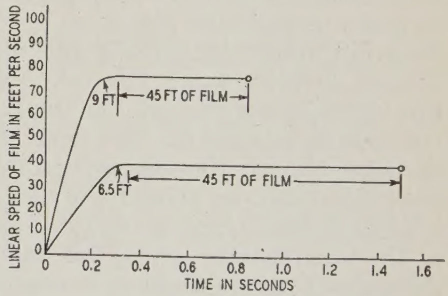
The particular method used in the circuit of Fig. 2 for obtaining an accurately controlled high voltage pulse to initiate the discharge in the tube is the use of a capacitor discharge through a step-up transformer. The capacitor C_2 (Fig. 2) is charged to about 900 volts through resistor R_2. During the charging cycle tube T_1 passes no current because the grid is connected so that it is negative with respect to the cathode (the drop through resistance R_2). A bleeder resistance R_4 passes enough current through R_2, after the condenser has been fully charged, to maintain sufficient bias to prevent the tube from firing.

The momentary charging surge of current into capacitor C_3 at the instant when the circuit to the commutator is closed puts a high positive potential on the grid of tube T_1 and causes it to conduct. In this circuit the tube acts as a switch that connects capacitor C_2 directly across the terminals of transformer T_2. A unidirectional surge of current flows through the primary and produces a surge of high voltage in the secondary which is connected to the external starting band of the tube. The secondary surge is oscillatory at a frequency determined by the inductance and distributed capacitance (also external capacitance). The polarity is adjusted so that the first wave is positive on the starting grid. Because of the oscillatory nature of the circuit consisting of capacitor C_2 and transformer T_2, tube T_1 is able to regain control, although connected to a source of direct current. After the surge of current through the primary, the voltage across the capacitor is opposite in sign because of the rectifying action of tube T_1, and by this time the grid again is negative and keeps the tube from starting as the capacitor again charges through R_2 in preparation for the next flash.

The upper limit of speed is determined by the deionization time of tube T_1, the characteristics of the particular transformer used, and the electrical time constants of the circuit. A speed of 6,000 pictures per second has been realized, using 2 tubes operating alternately into the same coil.

Internal structure of the camera is shown in Fig. 3. This camera purposely was designed to eliminate any sliding motion of the film against a gate or other part, since scratches, heat generation, and electrostatic sparks are caused by such friction. The disadvantage of the type shown is that the pictures are taken on the film while it is on a curved surface.

Fig. 4. Speed-time curves showing acceleration period and duration of a 60-ft length of film



Whether or not there is any appreciable distortion depends upon the diameter of the sprocket and the size of the frame, or individual picture. A compromise is made between a very large clumsy sprocket (and, incidentally, a large camera) with its difficulties of acceleration, and a small sprocket with its distortion. Consideration of these factors led to a main sprocket having a diameter of approximately

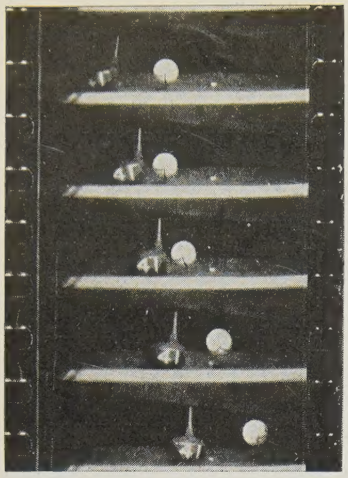


Fig. 5. High speed motion pictures showing impact of a golf club and ball taken at 980 pictures per second

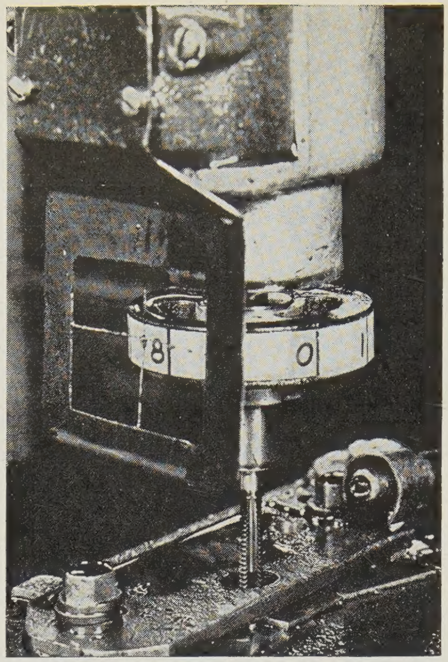


Fig. 6. View showing dial attached to automatic tapping chuck and cross wires for reference

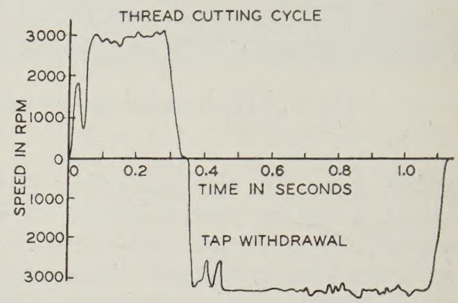


Fig. 7. Velocity-time relationships of automatic tapping machine shown in Fig. 6

5 in. with 20 standard 35-mm frames of film around its periphery. For this sprocket the center of the picture is 0.0295 in. closer to the lens plane than the extreme upper and lower edges of the frame. This distance is naturally smaller for pictures shorter than the full 35-mm frame height. Two square holes exactly the size of a 35-mm frame are placed diametrically in the sprocket for the purpose of alignment of the camera and for critical focusing of the lens, which is accomplished by the aid of a telescope in the back of the camera. This method has been found to be very effective, since the focus and alignment may be checked easily and accurately just before the camera is started. Many subjects are very close to the camera, and for this reason the depth of focus is small.

The film is pressed against the sprocket by an aluminum roller. Because of the friction of the teeth in the perforations, there is a considerable tendency for the film to stick to the sprocket, and for this reason a metal plow is placed under the sprocket in order to push the film from the teeth. This plow does not touch the film if the film comes off in a normal fashion, since the take-up motor pulls the film off before it reaches the plow. The function of the plow is to keep the film from winding around the sprocket should the take-up motor fail to keep the slack film taut, or should the film break.

Considerable care is required in the construction of the commutator, since the uniformity of framing depends on the perfection of commutator and brush rigging. As shown in Fig. 1, the commutator is on the same shaft as the sprocket and is placed outside the box in order to be readily accessible for inspection. Brush construction is important, since any vibration or bouncing will cause nonuniform spacing of the frames. This camera has small stranded copper brushes about $^1/_{16}$ in. in diameter, which are pressed against the commutator by springs. Adjustment is possible so that the location of the frame with respect to the sprocket holes may be determined. Since there is an inappreciable time lag in the electrical circuit after a segment of the commutator contacts the brushes, the brush adjustment can be made with the camera at rest. Two sets of brushes are shown which make it possible to flash 2 stroboscopic lamps in alternation for high speed pictures.

Driving motors have been selected to give rapid acceleration and to hold fairly constant speed after the film has been accelerated. A series motor is connected directly to the take-up reel at the bottom of the camera; it is operated on overvoltage in order to increase its accelerating torque so that it always tends to overdrive the film. The series motor contributes considerable acceleration to the main sprocket and to the supply reel, besides performing its function of reeling up the film as it comes through the camera. A 3-phase $^1/_4$-hp induction motor is belted to the camera shaft with a V belt, since changing pulleys is a convenient method of changing the speed. The motor is started with overvoltage in order to increase its accelerating torque. The speed-torque characteristics of the induction motor are such that the motor tends to run at a constant speed corresponding to the speed of the rotating field set up by the current in the armature windings. Since the load is small after the accelerating period, the motor will run close to synchronous speed, and the rate of taking the pictures is thereby fairly constant and known. Figure 4 shows speed-time curves of film in the camera for different conditions, and the amount of film used in the accelerating period.

Uses of the Camera and Examples

As has been mentioned before, motion pictures taken at a high rate of speed and projected at the normal rate of 16 per second show an action on the screen slowed down by the same factor by which the camera was speeded up. Pictures taken at the rate of 1,600 per second of an event having a duration of 0.1 sec show a projected movie of that event lasting

100 times longer, or 10 sec. This ability of high speed motion pictures to reduce the speed of action is one of the most important uses. Furthermore, the pictures may be projected as many times as desired, such a repeated study permitting the eye to become familiar with the motion. Often inconspicuous but important motions are not noticed until a film has been projected several times.

A high-speed motion-picture camera, especially the stroboscopic-light type just described, is useful for obtaining engineering data of the time relationships of displacements, velocities, accelerations, and the forms of objects. Such a camera is an instrument analogous to the oscillograph; it furnishes a time record of mechanical motion to the mechanical engineer, while the oscillograph plots a time record of electrical quantities for the electrical engineer.

Motion pictures taken with an ordinary camera or with high-speed motion-picture cameras of the moving-optical-system type have the disadvantage of a relatively long exposure time, resulting in blurred pictures of rapidly moving objects when close-up views are made for purposes of accurately measuring velocities and accelerations. A blurred image is an advantage when the pictures are projected on the screen as movies (since the images are blended in a natural way as seen by the eye), but it is not desirable when a study of individual frames is made by enlargements from the movie negative. The short exposure time of the stroboscopic light gives splendid pictures for enlargement and analysis, since the blur resulting from motion of the subject is negligible except for extremely high velocity.

Since velocity is the ratio of displacement to the time interval, the accuracy of determination of velocity depends upon the accuracy of measurement of the displacement on the film and the accuracy of the measurement of the elapsed interval of time. Usually the former is the most inaccurate because of the small size of the pictures, the grain size of the film emulsion, and blur resulting from motion during the time of exposure. An accuracy of 2 per cent is realizable using 35-mm film, and a comparator for measuring the displacement on the film. One method of determining the time is to put a timing record on the film by any of several well-known and often-used methods. Often the speed of the film is sufficiently constant because of the tendency of the induction motor to run at constant speed. Pictures taken purely for analysis and never to be projected may be taken with the flashing frequency controlled from a synchronously driven commutator or by an oscillator, as was done in determining the velocity of a golf ball. No definite relationship is needed between the flashing frequency and the speed of the film except that the film is made to move fast enough to prevent the pictures from overlapping.

A very good example to illustrate the method of measuring velocities is the analysis of a golf stroke. A series of instantaneous pictures taken at a rate of 960 per second is shown in Fig. 5. The velocities of the ball and club are determined by measuring the displacement of the ball and club from one picture to the next by means of a comparator. An analysis of the pictures shown in Fig. 5 resulted in the following data, which are accurate to within about 2 per cent for the translational velocities:

Initial club velocity just before impact.........	151 ft per second
Final club velocity just after impact...........	113 ft per second
Ball velocity..............................	186 ft per second
Spin of the ball............................	5,000 rpm

Since the masses of the ball and club are known there is sufficient information to calculate the energy lost by the club head and that gained by the ball, as well as to calculate the energy consumed in rotation of the ball. The pictures show definitely that the ball and club are in actual contact for less than 1/1,000 sec.

As a second example, the variations in angular velocity of the tap in an automatic tapping machine are plotted. A light aluminum disk attached to the chuck is divided into numbered sectors. Figure 6 shows this, as well as the set of cross wires that served as a reference for both angular and vertical linear motion. The instantaneous speeds during the working cycle, which lasted about 1 sec, are shown in Fig. 7.

These 2 examples chosen from several studies already made serve to demonstrate the great practical possibilities of this type of camera in the study of transient high speed motions in engineering apparatus.

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Step Type Feeder Voltage Regulators

A step type voltage regulator for electric power feeders has been designed, built, and tested in service, which is provided with steps so small as to give an operating curve as smooth as can be obtained with the induction regulator. In addition, the step type regulator has the advantage of lower cost, higher efficiency, lower exciting current, quieter operation, higher impulse strength, and suitability for high voltage applications.

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DEVELOPMENT of the step-type feeder-voltage regulator is a natural result of the development of tap-changing-under-load equipment for power transformers. It is interesting to note that in the early stages of the industry the problem of feeder voltage regulation was attacked first by using transformers and tap-changing-under-load equipment. The Stillwell regulator is an example of this. These early regulators were in general not successful because of trouble with burning of contacts and other mechanical difficulties, and after a relatively short time the induction regulator using a stationary winding and a rotatable winding came into use. This form of construction overcame the disadvantages of the early Stillwell regulator, and superseded the latter even though it had certain other less serious disadvantages. Development of the feeder regulator using the transformer and tap-changing-under-load principle practically ceased.

During these early years the possibility of changing taps under load on large power transformers was not even seriously considered. Even as late as 1921 and 1922 the application of tap-changing-under-load equipment to such a large unit of investment as a power transformer was a subject for considerable discussion. Transformer designers themselves were loath to "complicate" such a reliable piece of apparatus as a power transformer with tap-changing-under-load devices.

Starting about 1922, however, the demand for voltage regulation of large capacities for system interconnections and other applications became so pressing that manufacturers started to build tap-changing-under-load equipments for use with large transformers. The early units for this purpose were large, bulky, and very expensive, but in general they served their purpose well. Development during the intervening years has been rapid, and today there is no hesitation about applying tap-changing-under-load equipment to the largest transformers and for the highest operating voltages.

As soon as tap-changing-under-load equipment became commercially practicable for large power transformers, the demand became active for less expensive equipment for small power transformers. Naturally, the equipment designed for large power transformers could be used with small power transformers except that the cost became an unduly large percentage of the cost of the transformer. In answer to that demand, smaller, lighter, less expensive, tap-changing-under-load equipment using contactors or dial switches opening the circuit without the help of auxiliary circuit breakers was developed.

Development of equipment for small power transformers still left the need for still less expensive equipment for use in the equivalent of large distribution transformers or separate regulating units for regulating small and moderate capacity feeders of all voltages. The automatic feeder voltage regulator described in this paper was developed to meet this demand. The equipment has been designed with steps so small as to give as smooth an operating curve as can be obtained with the induction regulator; hence this equipment can meet the demand for regulation not only for applications where the cost of induction regulators has been prohibitive, but also for 2,400-volt applications where heretofore the induction regulator has been used exclusively.

Experience in the design and application of tap-

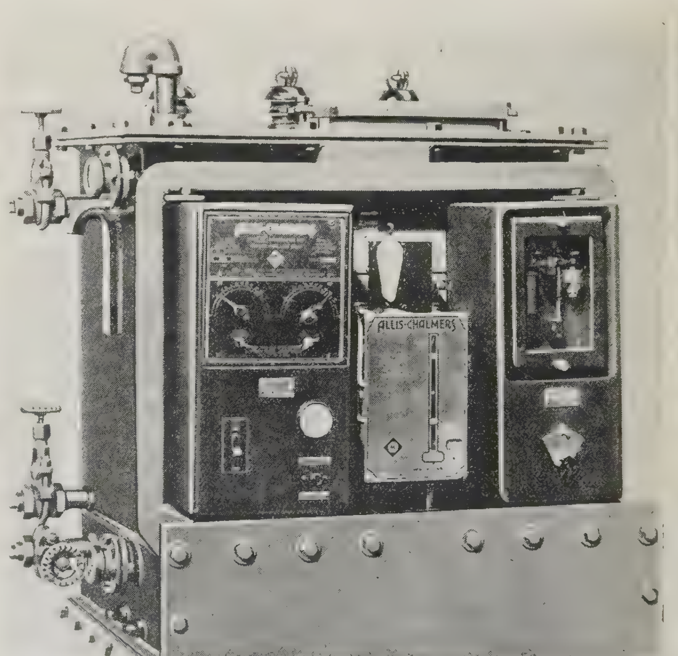

Fig. 1. Upper half of a 12-kva 50-ampere 2,400-volt outdoor regulator with cover over control panel removed

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changing-under-load equipments to large power transformers has been utilized fully. It is interesting to note that after all these years of development the tap-changing-under-load equipment as furnished by all manufacturers all over the world operates on substantially the Stillwell regulator principle, with the actual mechanical mechanisms, of course, quite different. The development therefore has been from the larger sizes back down to the smaller sizes with the fundamental scheme of operation the same, but with the mechanical operating means perfected through years of development.

With this step type regulator operating on the transformer and tap-changing-under-load principle, the usual range of plus and minus 10 per cent in voltage control under load is made in 32 $^5/_8$ per cent steps, which gives as smooth a voltage curve as can be obtained with the induction regulator and its associated relay. In other words, if the primary relay or contact making voltmeter is set at, say, plus or minus 1 per cent of the desired voltage, the induction regulator with its theoretically infinite steps can do no more than keep within this band of plus or minus 1 per cent. This step-type regulator with its $^5/_8$ per cent steps likewise can keep within this same band. Hence while the unit is theoretically a step type regulator, practically it is just as "stepless" as an induction regulator, judged by results obtained.

Advantages of the Step Type Regulator With Small Steps

The step type regulator with small steps has the following outstanding advantages over the induction regulator: First, it is lower in first cost, particularly in the larger sizes and the higher operating voltages, and can be built economically for higher voltages than could even be considered with an induction regulator. In addition the step type regulator has lower core and copper loss, and much lower exciting current. The exciting kilovoltamperes of an induction regulator is approximately 25 per cent of its kilovoltamperes rating, whereas the exciting kilovoltamperes of a step type regulator is less than $^1/_{10}$ of that amount. This represents an appreciable reduction in the exciting kilovoltamperes required to

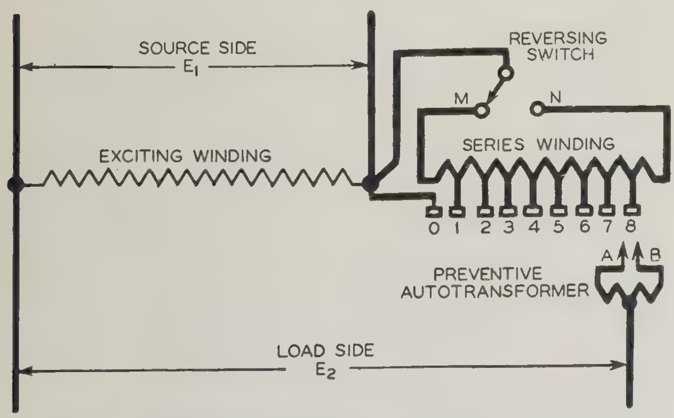


Fig. 2. Schematic diagram of single-phase step-type regulator

E_2 = 110 to 90 per cent of E_1 in 32 $^5/_8$ per cent steps

supply feeder regulators, and may be a very substantial item in a large system. Since the step type regulator uses transformer construction instead of motor construction, the impulse strength of the windings is much higher than can be attained with a winding lodged in slots, as in the induction regulator.

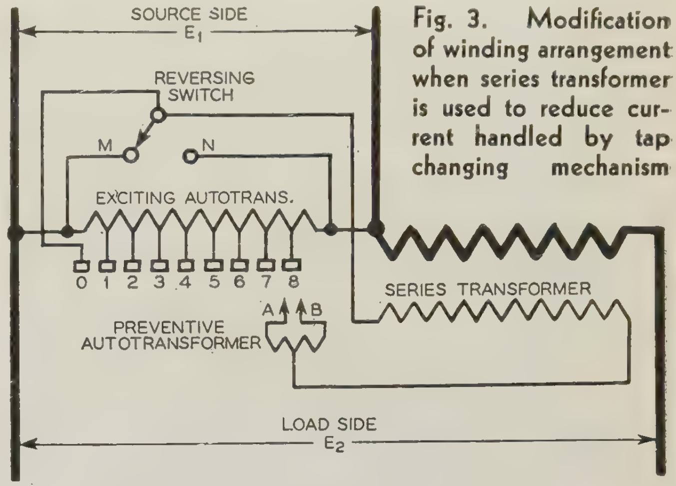


Fig. 3. Modification of winding arrangement when series transformer is used to reduce current handled by tap changing mechanism

E_2 = 110 to 90 per cent of E_1 in 32 $^5/_8$ per cent steps

The bushings of the step type regulator may be coordinated readily with the winding of the unit so that the bushings will flash over and prevent failure of the windings.

Figure 1 illustrates the upper half of a typical single phase unit with the control compartment cover removed. The tap changing mechanism is arranged in the lower portion under oil; this is separate from the oil in the upper portion which contains all the necessary transformers.

Scheme of Operation

A simple schematic diagram for a single phase unit showing the functioning of the various windings and mechanisms is shown in figure 2. The exciting winding of the transformer is shown connected across the line to be regulated. The series winding is provided with 8 taps which are connected to a tap-changing-under-load mechanism provided with an automatic mechanically operated reversing switch.

The 8 taps from the winding are connected to wide stationary contacts on the tap changing mechanism. Two moving contacts, *A* and *B*, which are connected to opposite ends of a midtapped autotransformer, are a fixed distance apart, and move as a unit with a snap action from one operating position to the next. The fixed space between these contacts is such that in any operating position either both are on the same wide stationary contact, or one is on each of 2 adjacent stationary contacts. The space between the stationary contacts is much greater than the width of moving contacts so that it cannot be bridged by the moving contacts.

To change taps from position 33, where contacts *A* and *B* are both on contact 8, to position 32, the moving contacts snap to a position where *A* is on

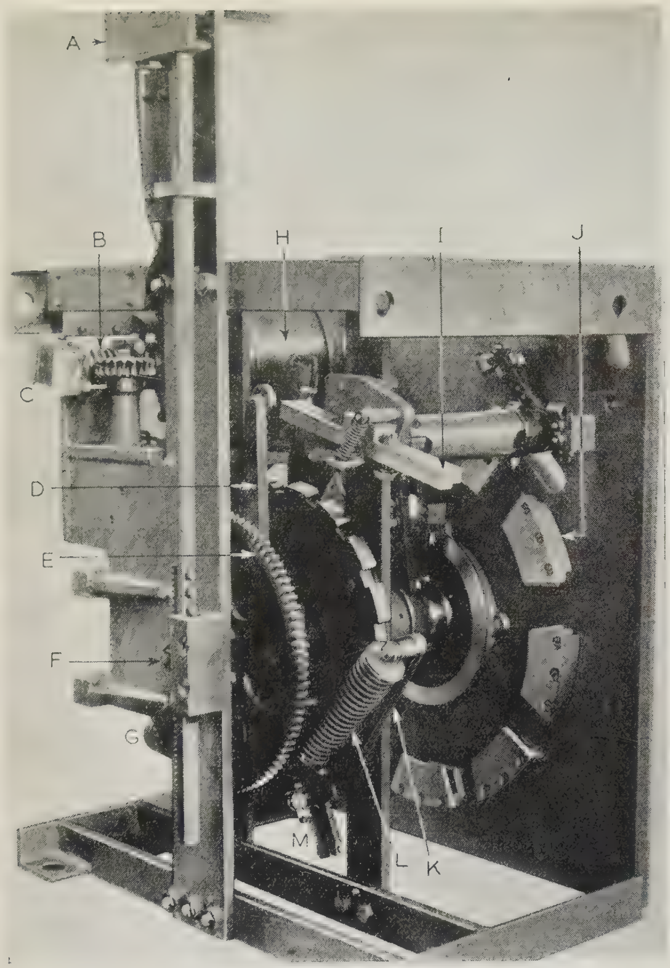


Fig. 4. Complete operating mechanism of single-phase step-type automatic feeder regulator

A. Position indicator
B. Worm and gear reduction
C. Provision for manual operation
D. Reversing switch operating arm
E. Worm gear reduction
F. Rack and pinion for operating position indicator
G. Driving spring
H. High-torque capacitor-type driving motor
I. Reversing switch operating mechanism and mechanical stop
J. Stationary contacts
K. Moving segment
L. Driving spring
M. Latch of quick-break mechanism

contact 7, but B is still on contact 8. During the instant that A is crossing the gap between contacts 8 and 7, the load current is carried entirely by the half of the autotransformer winding connected to B; but as soon as A is in contact with 7, the load current again will be divided equally between the 2 halves of the autotransformer winding, and the voltage obtained will be that midway between that of taps connected to contacts 7 and 8.

If the mechanism is moved on in a similar way until both A and B are on stationary contact 0, the voltage boost is reduced to zero, and no part of the tapped winding is in the circuit. If a still lower voltage is required, the reversing switch, which is now not in the circuit, is moved automatically from M to N while contacts A and B are still both on stationary contact 0. As the stationary contacts are arranged in a circle, the next movement will cause contacts A and B to snap to a position where A is on contact 8, but B is still on contact 0. This

Table I—Sequence of Operation of Regulator Shown in Figure 1 for ±10 Per Cent Range in Voltage

E_2 in Per Cent of E_1	Position No.	Contact A Connected to Tap No.	Contact B Connected to Tap No.	Reversing Switch on Contact
110	33	8	8	
109 3/8	32	7	8	
108 3/4	31	7	7	
108 1/8	30	6	7	
107 1/2	29	6	6	
106 7/8	28	5	6	
106 1/4	27	5	5	
105 5/8	26	4	5	
105	25	4	4	M
104 3/8	24	3	4	
103 3/4	23	3	3	
103 1/8	22	2	3	
102 1/2	21	2	2	
101 7/8	20	1	2	
101 1/4	19	1	1	
100 5/8	18	0	1	
100	17	0	0	
100	17	0	0	
99 3/8	16	8	0	
98 3/4	15	8	8	
98 1/8	14	7	8	
97 1/2	13	7	7	
96 7/8	12	6	7	
96 1/4	11	6	6	
95 5/8	10	5	6	
95	9	5	5	N
94 3/8	8	4	5	
93 3/4	7	4	4	
93 1/8	6	3	4	
92 1/2	5	3	3	
91 7/8	4	2	3	
91 1/4	3	2	2	
90 5/8	2	1	2	
90	1	1	1	

is position 16 in table I, and is the first buck position as the reversing switch has reversed the polarity of the tapped winding. The mechanism can be moved on until A and B are both again on contact 1, which corresponds to position 1 and which gives the maximum buck, or lowest voltage.

If it be desired to change the voltage in the other direction at any time, it is merely necessary to reverse the direction of the mechanism. Figure 3 shows the modification of the connections when a series tranformer is used to reduce the current handled by the tap changing switch.

Construction of Tap Changer

The tap-changing-under-load switch consists of an outer circle of 9 wide stationary segments and 2 inner concentric collector rings all mounted on a heavy bakelite plate, and 2 rotating contacts, A and B, mounted on a single bakelite arm (see figure 4). These moving contacts are a fixed distance apart and are insulated from each other, but each is connected to its collector ring. Each connection between these moving contacts and the stationary parts is made through a pair of contact fingers that wipe on both sides of the stationary members. The dynamic forces caused by heavy short-circuit currents therefore will increase the contact pressure. All contacts are renewable, and are made of nonarcing metal. The rotating arm is driven by an insulating shaft.

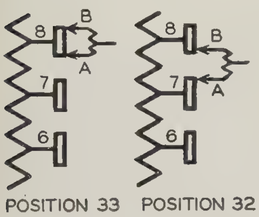
An important step in the development of this step type regulator was the development of a quick-break mechanism of unusual simplicity. The quick-break mechanism moves the contacts from one po-

sition to the next at a uniformly high speed, reducing contact deterioration. The design is such that when the quick-break mechanism operates, it automatically advances the moving contact assembly to the next operating position. Any tendency to pass beyond the normal operating position is arrested by the braking action developed by the driving spring for operation in the reverse direction. This provides an important self-centering feature without complication.

The entire tap changing mechanism, including the motor, operates under oil. This eliminates the necessity of oiling any parts of the mechanism. The oil in the tap changer compartment is entirely separate from the oil in the transformer compartment.

Determination of Size of Step

In the design of the step type regulator $^5/_8$ per cent steps with half-cycling operation were selected as representing the best engineering and economic solution to the problem. The smaller the step the smaller the voltage and kilovoltamperes to be interrupted, and hence the smaller the contact deterioration.



Position No.	Connections: A to Tap No.	Connections: B to Tap No.
33	8	8
	Open	8
32	7	8
	7	Open
31	7	7

Fig. 5. Diagram illustrating full-cycling and half-cycling operations

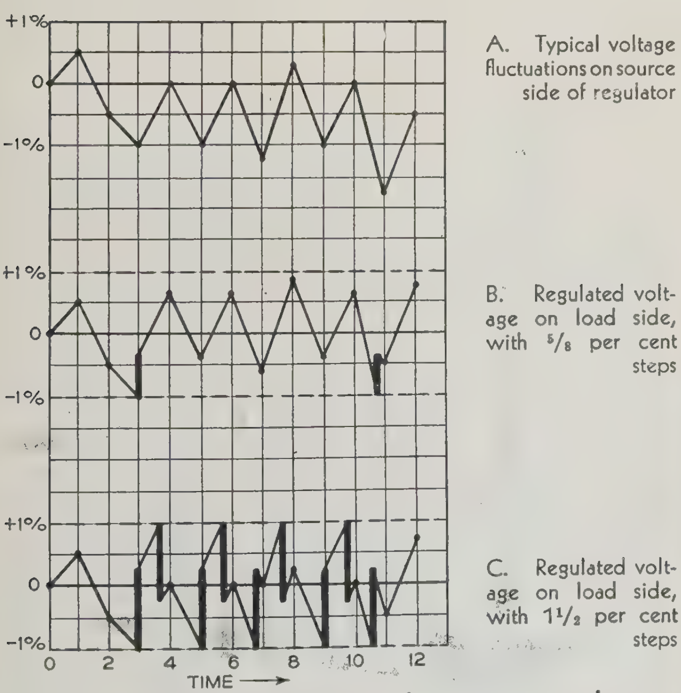


Fig. 6. Curves showing effect of step size on number of tap changing operations

Tap change operations indicated by heavy vertical lines

Whether half-cycling or full-cycling operation is used also has an important bearing on the subject. With full-cycling operation a physical tap is used for each operating voltage. With half-cycling operation the bridging position between 2 physical taps is used to provide an additional operating position. The 2 conditions are illustrated in figure 5. It may be seen that for $1^1/_4$ per cent steps with full-cycling operation there are 2 circuit openings and 2 circuit closings for each tap change. The duty is just twice what it is for a regulator using half-cycling operation and giving $^5/_8$ per cent steps.

The use of $^5/_8$ per cent steps is advantageous also because with the fluctuating voltages encountered in the average regulator service, the smaller steps will result in fewer tap changing operations.

When comparing the size of step and the number of operations the same setting of the primary relay or contact making voltmeter naturally must be considered. If the relay is to be set for close control on one regulator, the operation of the other regulator must be considered for the same setting.

Figure 6*A* indicates a succession of typical voltage fluctuations at the source side of a feeder regulator. In other words, there is first a fluctuation of $^1/_2$ per cent in voltage above the normal or desired voltage, then there is a change of 1 per cent in the opposite direction, and so on. Figures 6*B* and 6*C* indicate the voltages developed on the load side of a regulator under the conditions given in figure 6*A*. In both cases the relays are assumed to be set to operate at 1 per cent above or below the desired value to be maintained. Figure 6*B* indicates the effect with $^5/_8$ per cent steps, and 6*C* the effect with $1^1/_4$ per cent steps. By following through step by step it may be seen that the output voltages of the 2 regulators fluctuate in a different manner because of the fact that one step is $^5/_8$ per cent and the other is $1^1/_4$ per cent. Both regulators in this case keep the voltages within the band determined by the setting of the primary relay, but the number of operations is greater with $1^1/_4$ per cent steps than it is with $^5/_8$ per cent steps. There are 9 tap changes with the $1^1/_4$ per cent step regulator and only 2 with the $^5/_8$ per cent step regulator. If a regulator with $2^1/_2$ per cent steps were used , it is obvious that a relay setting as

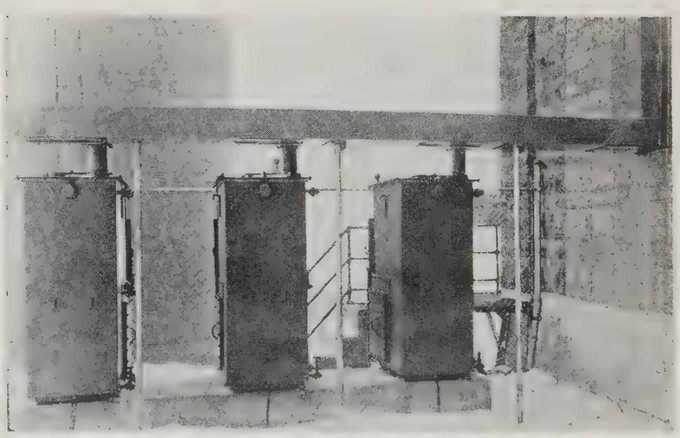


Fig. 7. Installation of 3 72-kva single-phase 300-ampere 2,400/4,160-volt regulators

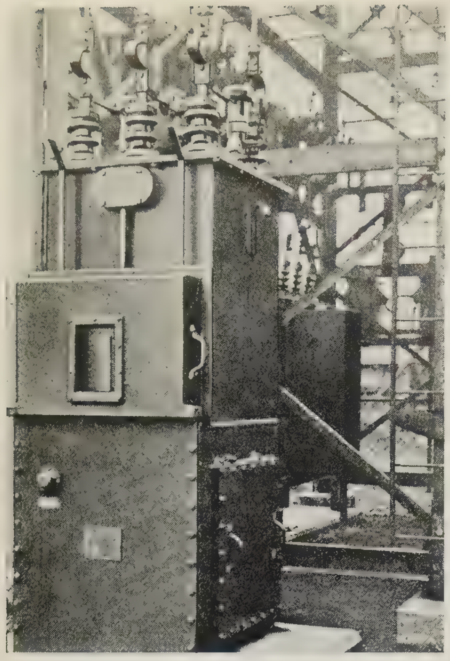


Fig. 8. Installation of 6,900-volt 50-ampere 60-kva 3-phase feeder regulator

close as plus or minus 1 per cent could not be used practically, because if the "lower" contact of the relay closed and caused the tap changer to move, the step would be so large as to cause the "raise" contact to close and make a tap change in the opposite direction. The regulator therefore would "hunt" and the relay contacts would have to be set farther apart to prevent this.

It may be seen from this analysis that the reason for $1^1/_4$ per cent steps giving more operations than $^5/_8$ per cent steps is that $1^1/_4$ per cent steps overcorrect the voltage condition so that a change in system voltage in the reverse direction calls for a tap change sooner than it otherwise would. The effect is similar to the condition that prevails when the brake on an induction regulator fails to hold properly and the regulator coasts.

Automatic Control

The step type regulator readily may be arranged for full automatic voltage regulation, with line drop compensation if desired. A primary relay responsive to the feeder voltage controls a time delay contactor, which in turn controls the main driving motor. If the primary relay is unbalanced and makes contact without interruption for the length of time required by the time delay contactor, the latter will close the main motor circuit for the direction of rotation required to correct the feeder voltage, and in a few more seconds the mechanism will move one step. If the resulting change in feeder voltage does not balance the primary relay, a second step and as many more as are required will follow at intervals of a few seconds each. Whenever the primary relay balances, the time delay contactor resets instantly and the motor stops. The motor cannot start again until the primary relay again has been unbalanced without interruption for the period required by the time delay contactor.

The equipment for automatic control is enclosed in the housing on the front of the regulator tank. In the center of this housing, and visible through a safety glass window, is the mechanical position indicator. On each side of the position indicator is a steel cabinet panel. The control devices are housed in these cabinets.

Antihunting Control

In order that the regulator will operate only when a tap change is really necessary, a time delay is interposed between the closing of the primary relay contacts and the starting of the tap-changing operating motor. The primary relay starts the geared time-delay contactor. After an interval that may be set up to 55 or 60 seconds, which is sufficient to indicate that the voltage change is not a momentary fluctuation, the time delay contactor closes its "raise" or "lower" contact to run the operating motor in the proper direction. If normal voltage is restored during the initial time delay, the contactor will reset.

The use of a time delay contactor eliminates needless operations of the regulator due to line fluctuations that shortly would correct themselves without operation of the regulator, but causes the voltage to be brought back to normal if the correction actually is needed. Should the voltage change on the line be large and require more than one tap change to correct it, the use of this separate time-delay contactor permits the regulator to make as many tap changes as are necessary, one after the other, without repeating the initial time delay between operations. The time delay could be built directly into the operating mechanism of the tap changing device, but this would introduce the time delay mentioned between each 2 successive tap changes, and also cause the mechanism itself to be operated needlessly.

Figure 7 illustrates an installation of single-phase regulators, and figures 8 and 9 illustrate typical 3-phase installations.

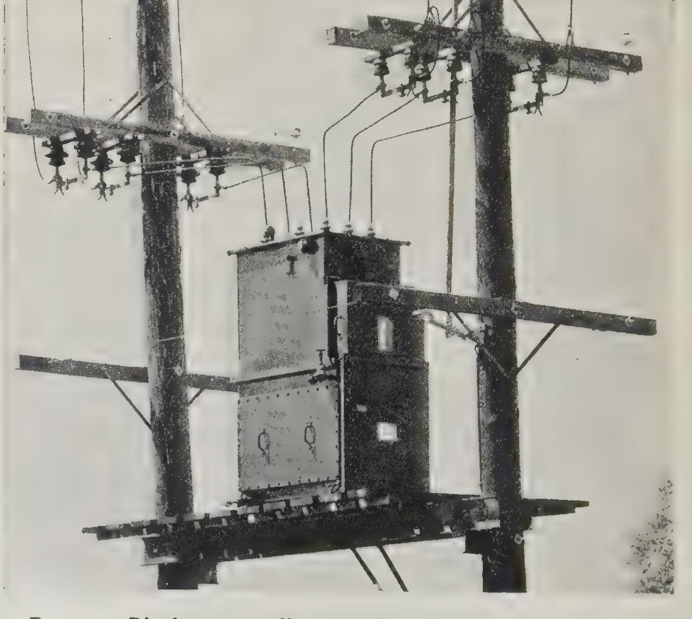


Fig. 9. Platform installation of 54-kva 3-phase 4,160-volt feeder regulator

Experimental Analysis of Double Unbalances

Double unbalances in 3-phase electric power networks may be analyzed experimentally on the network "calculating board" by applying the method of symmetrical components; 2 such methods of analysis are presented in this paper. Although intended primarily for use with the a-c calculating board, some of the material is applicable to the d-c board and to the purely mathematical solution of networks.

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ANALYSIS of 3-phase networks under unbalanced conditions, such as single-phase short circuits, is important to power system engineers who are called upon to deal with the problems of stability and of the operation of protective relays. Before the development of the method of symmetrical components,[1,2] short-circuit studies commonly were confined to 3-phase short circuits, and the currents during single-phase short circuits were estimated by multiplying the 3-phase short-circuit currents by an "experience factor."

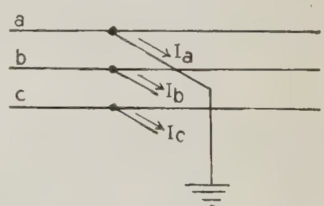
Present methods of dealing with single unbalances on 3-phase networks by the method of symmetrical components are well known and widely used.[2] However, the methods of analyzing double unbalances (this term is defined later in the paper) are not so well known, although Edith Clarke has written an excellent paper on "Simultaneous Faults."[3] The purpose of the present paper is to elucidate further the treatment of double unbalances and to present the author's contributions to the subject, which include: (1) the connection of the sequence networks by transformers and by phase converters; (2) the modified π equivalent circuit; (3) application of the theory to simultaneous faults on opposite sides of a Δ-Y transformer bank; (4) application of the theory to combined series and shunt unbalances.

Networks may be analyzed either mathematically or experimentally. Several mathematical methods are available: (1) solution of simultaneous equations based upon Kirchhoff's laws; (2) cut-and-try method; (3) simplification of the network by repeated Y-Δ and Δ-Y transformations. When the network is complicated the calculations are very laborious by any of these methods, and the experimental method becomes preferable. In the experimental method the power network is represented to scale by a miniature network, the required currents and voltages being measured with instruments. Such miniature networks, also called "calculating tables" or "calculating boards" are made in both d-c and a-c forms. In using the d-c board the resistance and capacitance of the a-c power circuits are neglected, and their reactance is represented by resistance; generator voltages, which must be assumed to be in phase with each other, are represented by d-c voltages. In the a-c board[4,5] resistors, reactors, and capacitors are provided, and generators are represented by phase shifters, which give a-c voltages adjustable in both phase and magnitude. Obviously, the a-c board is more accurate and also more expensive than the d-c board.

In this paper double unbalances will be discussed primarily from the viewpoint of their solution on the a-c calculating board. However, some of the material is applicable to the d-c board and to the purely mathematical solution of networks. By either of 2 methods, the connection method or the equivalent circuit method, the currents and voltages in all parts of a 3-phase network on which there is a double unbalance (either 2 shunt unbalances, or a combined series and shunt unbalance) may be determined conveniently on an a-c calculating board.

In using the connection method all 3 sequence networks are set up at the same time and the unbalance is represented by appropriate connections between the networks, whereupon the currents and

Fig. 1. Line-to-ground short circuit on one phase of a 3-phase network



voltages in each sequence network represent to scale the corresponding symmetrical components of current and voltage in the unbalanced 3-phase system. In making the connections between the sequence networks, insulating transformers are sometimes necessary, and phase converters must be used for unbalances not symmetrical with respect to any phase.

In the equivalent circuit method the sequence networks may be set up separately. The unbalance is represented in the positive sequence network by the connection of a 3-terminal equivalent circuit to the 2 points of unbalance and to the ground terminal. If the unbalance is not symmetrical with respect to any phase, its equivalent circuit cannot be passive, but must contain either phase converters or adjustable electromotive forces. Some equivalent circuits

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The writer wishes to acknowledge his indebtedness to Prof. H. L. Hazen, who gave a great many helpful suggestions.

1. For all numbered references see list at end of paper.

contain negative resistances, which may be obtained practically in several ways.

Single Unbalances

Before proceeding to the discussion of double unbalances, the meaning of the terms "connection method" and "equivalent circuit method" will be illustrated by reviewing the application of each method to the solution of a network having a single unbalance. The notation used throughout the paper will be as follows:

E = voltage to ground at point of unbalance

I = current flowing into unbalance

Z = impedance of balanced network, measured from point of unbalance

x and y, as subscripts, indicate the 2 points of unbalance, that is, the points at which a double unbalance is connected to the balanced network

a, b, and c, as subscripts, indicate phases of a 3-phase system

0, 1, and 2, as subscripts, indicate phase sequence of symmetrical components

Primes (′) denote calculating board quantities where it is necessary to distinguish them from actual power system quantities

$a = \epsilon^{j\frac{2\pi}{3}}$ is an operator rotating a vector 120 deg forward

All quantities are complex.

Connection Method. First, the 3-phase network is represented on the calculating board by setting up its 3 sequence networks (positive, negative, and zero sequence). The positive sequence network contains electromotive forces, which may be adjusted to conform to normal operating conditions before the occurrence of an unbalance, but the negative and zero sequence networks are dead. Second, to represent the unbalance, a connection is made between the sequence networks at the point of unbalance. The nature of this connection depends on the type of unbalance and may be found in the following manner: Write 3 equations giving particular values of, or relationships between, the currents flowing into the unbalance and the voltages to ground at the point of unbalance. For example, for a line-to-ground short circuit on phase a (Fig. 1), the voltage of the grounded phase is zero and the currents flowing into the unbalance from the 2 ungrounded phases are zero:

$$E_a = 0 \qquad I_b = 0 \qquad I_c = 0 \tag{1}$$

Convert these relations into 3 equivalent relations between the symmetrical components of current and voltage by making the mathematical substitution that is the basis of the method of symmetrical components. The result is:

$$E_0 + E_1 + E_2 = 0 \qquad I_0 = I_1 = I_2 \tag{2}$$

These relations are satisfied by a series connection of the 3 sequence networks at the point of short circuit (Fig. 2).

In a similar way it may be shown that a parallel connection of the 3 sequence networks represents a double line-to-ground short circuit on phases b and c, while a parallel connection of the positive and negative networks only represents a line-to-line short circuit on phases b and c.

Having made the appropriate connections between sequence networks on the calculating board, the voltages and currents are measured at the desired points. The positive sequence voltages and currents are measured in the positive sequence network and the negative and zero sequence quantities in their respective networks. (On the a-c board the measurements include phase angle, as well as magnitude.) The actual voltages and currents then may be found by properly combining the symmetrical components.

Equivalent Circuit Method. There are 2 reasons why the connection method may not always be suitable: (1) the unbalance may be of a type not readily represented by a connection between the sequence networks; or (2) the 3-phase network may be so large that not enough impedance units are available to set up the 3 sequence networks simultaneously. In such cases the second or "equivalent circuit" method may be used. The procedure is as follows: Set up the negative and zero sequence networks and measure the impedance of each between line and ground at the point of unbalance. Then set up the positive sequence network, and at the point of unbalance shunt it with an impedance the value of which depends on the measured impedances and on the type of unbalance. For a line-to-ground short circuit this impedance is $Z_0 + Z_2$, for a line-to-line short circuit it is Z_2, and for a double line-to-ground short circuit $\frac{Z_0Z_2}{Z_0 + Z_2}$, where Z_0 and Z_2 denote the measured impedances of the zero and negative sequence networks, respectively. The expression for this equivalent fault impedance may be written from inspection of the connections between sequence networks used in the connection method; or it may be found by reducing 5 equations in E_0, E_1, E_2, I_0, I_1, and I_2 to one equation of the form

$$E_1 = ZI_1 \tag{3}$$

in which Z is the impedance sought. The 5 equa-

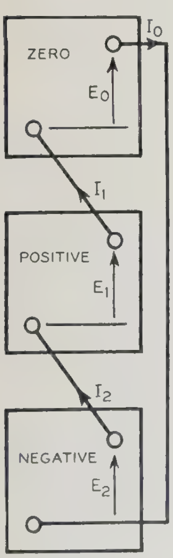


Fig. 2 (left). Series connection of the 3 sequence networks for representing a line-to-ground short circuit

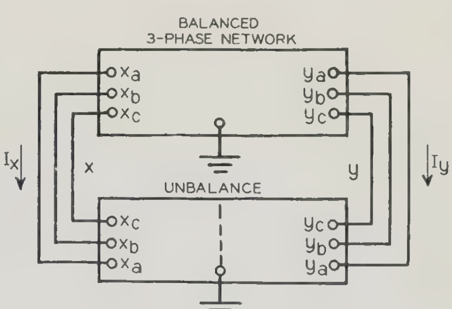


Fig. 3. Double unbalance, connected to a balanced 3-phase network at the 2 points of unbalance x and y

tions consist of 3 pertaining to the unbalance itself and independent of the rest of the network (for example, eqs 2 for a line-to-ground short circuit) and the following 2 pertaining to the balanced portion of the network and independent of the type of unbalance:

$$-E_0 = Z_0 I_0 \qquad -E_2 = Z_2 I_2 \tag{4}$$

After connecting the proper impedance in shunt with the positive sequence network, the positive sequence currents and voltages are measured at the point of unbalance and wherever else they are desired.

Next the negative sequence network is set up again, and a voltage is applied to it at the point of unbalance. This voltage is adjusted until either the voltage or the current at this point bears the proper relation to the positive sequence voltage or current which already has been measured. Thus for a line-to-ground short circuit $I_2 = I_1$, while for a double line-to-ground fault $E_2 = E_1$. After the applied voltage has been adjusted, negative sequence currents and voltages may be measured throughout the network. The zero sequence network is solved in a similar manner.

In short, by the connection method the 3 sequence networks are solved simultaneously, whereas by the equivalent circuit method they are solved separately.

Series Unbalances. The foregoing discussion of single unbalances deals primarily with short circuits and other shunt unbalances. Open circuits and other series unbalances are handled in a similar way, but with the following difference: Each sequence network presents 2 terminals at the point of unbalance, these terminals being used for connecting the networks in applying the connection method or measuring network impedances, connecting equivalent fault impedances, and applying voltages in using the equivalent circuit method. When dealing with shunt unbalances these terminals are *line* and *ground* at the point of unbalance, but when dealing with series unbalances they are the line side of the circuit on each side of the series unbalance.

Double Unbalances

Sometimes short circuits occur simultaneously at 2 or more points of a power system, or open circuits and short circuits may exist concurrently. Again, one may wish to investigate the effect of 2 or more single-phase or unbalanced loads. All these conditions may be classed as double (or multiple) unbalances.

A double unbalance may be defined as an unbalance that is connected to a balanced polyphase network at 2 points (Fig. 3) provided that both the currents and the voltages differ at the 2 points. If the currents are equal the double unbalance reduces to a single series unbalance; if the voltages are equal it reduces to a single shunt unbalance. There are 2 principal classes of double unbalance: (1) 2 simultaneous shunt unbalances, and (2) combined series and shunt unbalances. In class 1 the unbalanced portion of the network can be divided into 2 independent parts, as shown by the dotted line in Fig. 3, while in class 2 it cannot.

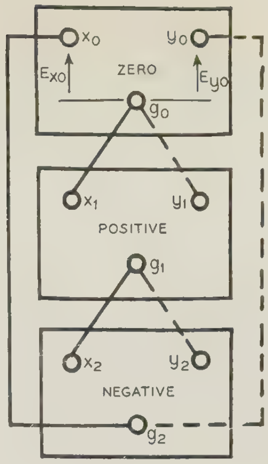


Fig. 4. Wrong method of connecting the sequence networks to represent 2 line-to-ground short circuits on phase a

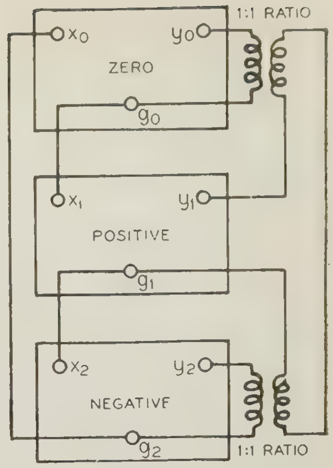


Fig. 5. Correct method of connecting the sequence networks to represent 2 line-to-ground short circuits on phase a. One of the series connections is made through insulating transformers

In solving double unbalances on the calculating board, either the connection method or the equivalent circuit method can be used.

Connection Method. When the balanced portion of a 3-phase network having a double unbalance is represented by its sequence networks, each of the latter has 3 terminals to be considered: the ground terminal (g, Fig. 4) and the line terminal at each of the 2 points of unbalance (x and y). The current flowing out of terminal x will be denoted by I_x, and that flowing out of terminal y by I_y; the voltages of x and y with respect to g will be denoted by E_x and E_y, respectively. Subscripts a, b, and c will be added to denote phase, or 0, 1, and 2 to denote phase sequence.

In applying the connection method to double unbalances it is necessary to connect the 9 terminals (3 on each sequence network) in such a way as to represent the particular unbalance in question. In doing so some problems arise that did not arise in the case of a single unbalance.

Consider the specific example of 2 line-to-ground short circuits, one at point x and one at y, both on phase a. The current and voltage relations at each point are the same as those already written for a single short circuit of this kind:

$$\begin{array}{lll} \text{At } x, & E_{x0} + E_{x1} + E_{x2} = 0 & I_{x0} = I_{x1} = I_{x2} \\ \text{At } y, & E_{y0} + E_{y1} + E_{y2} = 0 & I_{y0} = I_{y1} = I_{y2} \end{array} \tag{5}$$

Since a series connection of the sequence networks corresponded to a single ground fault, it is only natural to try making a series connection at each point, as shown in Fig. 4. These connections certainly satisfy the voltage equations, but there is no assurance that they satisfy the current equations; this is because there is no longer a simple series circuit, but rather 2 series circuits interconnected at several points. This difficulty may be avoided by making one of the series connections through the medium of in-

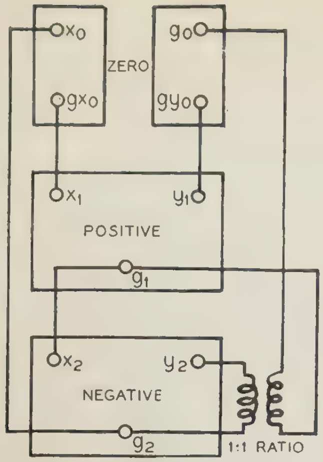
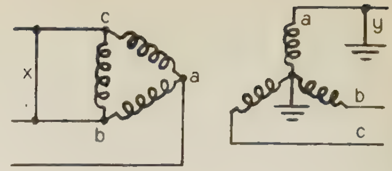
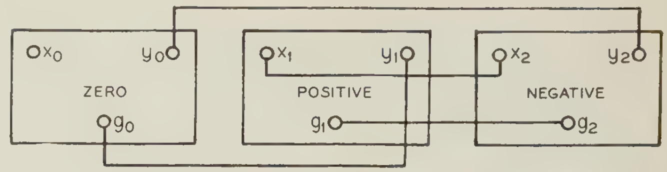


Fig. 6 (left). Connections of the sequence networks corresponding to 2 line-to-ground short circuits at points on opposite sides of a Δ-Y transformer bank

Fig. 7 (right). Connections of the sequence networks corresponding to a short circuit between phases b and c at point x and a short circuit from phase a to ground at point y, points x and y being separated by a Δ-Y transformer bank





sulating transformers of 1 to 1 ratio (Fig. 5). Such a connection satisfies the requirements given by eqs 5, and, the connection having been made, the rest of the procedure for solving the network is exactly the same as for a single unbalance.

In the example just considered both short circuits were on the same phase. Suppose now that the short circuit at point x is on phase a as before, but that the one at y is on phase b. The equations for point x are the same as before, but those for y now become:

$$E_{y0} + a^2E_{y1} + aE_{y2} = 0 \qquad I_{y0} = a^2I_{y1} = aI_{y2} \tag{6}$$

differing from the previous equations for point y by the presence of the operators a and a^2 which signify phase advances of 120 and 240 deg, respectively. The equations for point x are satisfied by the series connection as before, while those for point y are satisfied by a series connection made through phase converters instead of through transformers. The phase converter is a device having 2 pairs of terminals and so designed that the current and voltage of one pair of terminals are equal in magnitude to, but 120 deg in phase from, the current and voltage, respectively, of the other pair. The design of such a device is discussed in a later section of this paper.

By the use of transformers and phase converters in conjunction with the a-c calculating board, it is possible to apply the connection method to the solution of a 3-phase network having any number and any combination of types of simultaneous short circuits. Each short circuit is represented by a connection between the sequence networks at the point of fault. In making the connections, transformers are used where necessary to insulate circuits from one another without shift of phase, and phase converters where it is necessary to shift phase. Phase converters are required only for those short circuits not symmetrical with respect to phase a. In dealing with a single short circuit, it is always possible to name the phases so that the short circuit is symmetrical with respect to phase a (that is, to take a line-to-ground fault on phase a, and double line-to-ground or line-to-line fault on phases b and c). In dealing with simultaneous short circuits, however, it is generally impossible to name the phases in this manner for each short circuit, but it can be done for at least one of them. A few simultaneous short circuits require neither transformers nor phase converters. For such faults the connection method can be used on the d-c calculating board.

Simultaneous Faults on Opposite Sides of a Δ-Y Transformer Bank. A slight change of procedure is required for representing 2 short circuits on opposite sides of a Δ-Y transformer bank, because of the 90-deg phase shift produced by the transformers which does not have a counterpart in the representation of the transformers on the calculating board. (See p. 65 of reference 2.) The phase shift may be regarded as 30, 90, or 150 deg, depending on the designation of the phases of the 2 circuits; but the choice of 90 deg is most convenient for computation with complex numbers. Positive sequence currents and voltages are shifted 90 deg ahead (or behind, depending on the actual transformer connections) in passing through the bank, whereas negative sequence currents and voltages are shifted 90 deg in the opposite direction. Zero sequence currents and voltages are not transmitted through a Δ-Y bank. The net result is a phase reversal of the negative sequence quantities with respect to the positive sequence quantities on one side of the transformer bank. Arbitrarily taking the phases on side x as standard, and denoting calculating-board quantities by primed letters and actual system quantities by unprimed letters:

On side x, $\quad E_{x1} = E_{x1}', \quad E_{x2} = E_{x2}', \quad$ and $E_{x0} = E_{x0}'$
On side y, $\quad E_{y1} = jE_{y1}', \quad E_{y2} = -jE_{y2}', \quad$ and $E_{y0} = E_{y0}' \qquad (7)$

and similarly for currents.

Consider again 2 line-to-ground faults on phase a, one at point x and the other at y, the points now being taken on opposite sides of a Δ-Y transformer bank. The current and voltage relations are given by eqs 5 and the calculating-board current and voltage relations are found by using eqs 7. At point x the calculating-board current and voltage relations are the same as before and are satisfied by the usual series connections, but at y they become:

$$E_{y0}' + jE_{y1}' - jE_{y2}' = 0 \qquad I_{y0}' = jI_{y1}' = -jI_{y2}' \tag{8}$$

or, multiplying by $-j$:

$$-jE_{y0}' + E_{y1}' - E_{y2}' = 0 \qquad -jI_{y0}' = I_{y1}' = -I_{y2}' \tag{9}$$

These equations are satisfied by a series connection at point y, in which the connection to the negative sequence network is reversed and the connection to the zero sequence network is made through a phase converter giving a phase shift of 90 deg. The phase converter is not really necessary, however, and can be replaced by an insulating transformer if the zero

sequence network on one side of the Δ-Y bank is independent of that on the other side, as it practically always is. The 90-deg phase shift is taken into account later. Even the transformer can be dispensed with if the zero sequence network is set up in 2 parts with separate ground terminals, the connections then being as shown in Fig. 6.

The rules for handling any simultaneous faults on opposite sides of a Δ-Y transformer bank are: Set up the zero sequence network in 2 separate parts, each having its own ground terminal. Make connections between the networks just the same as usual except that on one side (say y) the negative sequence network is connected with reversed polarity. Multiply the measured negative sequence currents and voltages on this side of the transformers by $-j$ and the positive and zero sequence quantities by j before combining them to obtain phase quantities; or, if there is no objection to choosing a different reference axis for quantities on the y side, simply multiply the negative sequence quantities on this side by -1, leaving the positive and zero sequence quantities unchanged.

Another example is shown in Fig. 7. This example could be solved on the d-c board, since no special apparatus is required.

Combined Series and Shunt Unbalances. Unbalances of this type may be solved on the calculating board in the same way as simultaneous faults. It is always possible to write 6 relations between the sequence currents and voltages at points x and y, and the connections between the sequence networks must conform to these relations. Two examples follow, in which the connections corresponding to combined series and shunt unbalances are derived.

In Fig. 8 is shown a kind of unbalance that might occur if one conductor of a 3-phase line should break and one end of it should fall onto the ground. Such an unbalance might occur also during a line-to-ground short circuit on a line equipped with single pole switching, assuming the circuit-breaker at the end of the line nearest the fault to open sooner than the one at the far end. The unbalance consists of a short circuit next to an open circuit. The current and voltage relations are as follows:

For the ground on phase a:

$$E_{xa} = 0 \qquad I_{xb} + I_{yb} = 0 \qquad I_{xc} + I_{yc} = 0 \tag{10}$$

For the open circuit on phase a:

$$I_{ya} = 0 \qquad E_{xb} - E_{yb} = 0 \qquad E_{xc} - E_{yc} = 0 \tag{11}$$

In terms of symmetrical components the relations become:

For the ground,

$$E_{x0} + E_{x1} + E_{x2} = 0; \quad I_{x0} + I_{y0} = I_{x1} + I_{x2} = I_{y1} + I_{y2} \tag{12}$$

For the open circuit,

$$I_{y0} + I_{y1} + I_{y2} = 0; \; E_{x0} - E_{y0} = E_{x1} - E_{y1} = E_{x2} - E_{y2} \tag{13}$$

The connections of Fig. 9 meet the requirements. The short circuit is represented by a series connection of the networks between x and ground, the open circuit by a parallel connection between x and y.

Another type of unbalance, which could occur if a cable were incorrectly spliced and then switched into service, is shown in Fig. 10. The relations between phase currents and voltages are:

$$\begin{aligned} E_{xa} &= E_{ya} & I_{xa} &= -I_{ya} \\ E_{xb} &= E_{yc} & I_{xb} &= -I_{yc} \\ E_{xc} &= E_{yb} & I_{xc} &= -I_{yb} \end{aligned} \tag{14}$$

The corresponding relations between symmetrical components are:

$$\begin{aligned} E_{x0} &= E_{y0} & I_{x0} &= -I_{y0} \\ E_{x1} &= E_{y2} & I_{x1} &= -I_{y2} \\ E_{x2} &= E_{y1} & I_{x2} &= -I_{y1} \end{aligned} \tag{15}$$

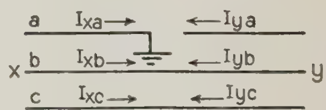
Connections between the sequence networks satisfying these relations are shown in Fig. 11. These connections can be made on either the a-c or the d-c board. Although the zero sequence network is shown in the figure, it is not necessary to set it up because the zero sequence currents and voltages are all zero.

Many other examples of combined series and shunt unbalances could be given, but it is believed that enough have been given to illustrate the application of the connection method. Attention now will be turned to the handling of double unbalances by the equivalent circuit method.

Equivalent Circuit Method. The equivalent circuit for representing a single unbalance in the positive sequence network is a single impedance connected in shunt (or series) with the positive sequence network at the point of unbalance. The equivalent circuit of a double unbalance must be some form of 3-terminal network. The simplest forms are the T and the Π. The ordinary T or Π may be used as an equivalent circuit for a double unbalance that is symmetrical with respect to any one phase. If, however, the double unbalance is unsymmetrical, the T or Π circuit must be modified by the addition of one or more phase converters or sources of electromotive force.

The equivalent circuit for any particular unbalance may be derived readily in some cases by "boiling down" the circuits used in the connection method, first replacing the negative and zero sequence networks by their equivalent T's or Π's (based upon impedance measurements at terminals x, y, and g). The equivalent circuit of a double unbalance may be derived also by the following procedure developed by Miss Clarke:[3] 10 equations are written in the 12

Fig. 8. Unbalance consisting of an open circuit and a ground



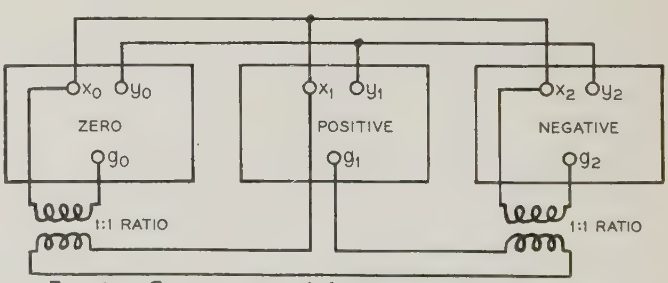
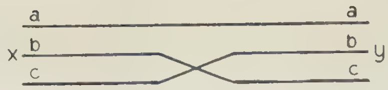


Fig. 9. Connections of the sequence networks corresponding to the unbalance of Fig. 8

Fig. 10. Unbalance in which phases b and c are interchanged



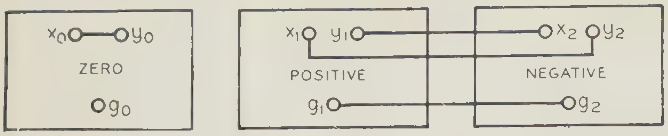


Fig. 11. Connections of the sequence networks corresponding to the unbalance of Fig. 10

unknown currents and voltages E_{x0}, E_{x1}, E_{x2}, E_{y0}, E_{y1}, E_{y2}, I_{x0}, I_{x1}, I_{x2}, I_{y0}, I_{y1}, and I_{y2}. Of these equations 6 pertain to the unbalance and examples of them have been given in describing the connection method; 4 pertain to the balanced part of the network, 2 for negative and 2 for zero sequence. The 10 equations then are reduced to 2 equations in E_{x1}, E_{y1}, I_{x1}, and I_{y1}, which may be written in the form

$$E_{x1} = kI_{x1} + mI_{y1} \qquad E_{y1} = nI_{x1} + lI_{y1} \tag{16}$$

or in the alternative form

$$I_{x1} = pE_{x1} + qE_{y1} \qquad I_{y1} = rE_{x1} + sE_{y1} \tag{17}$$

An equivalent circuit based upon eqs 16 is shown in Fig. 12. This is the modified T circuit. The agreement of this circuit with eqs 16 may be verified by adding the IZ drops from terminal g to terminal x or y. In order to obtain the current $I_{y1} - I_{x1}$ in the impedance $(m-n)/2$, it is necessary to shunt this impedance with a source of electromotive force adjusted in phase and magnitude until the current from this source is $2I_{x1}$, which subtracts from the current $I_{x1} + I_{y1}$ otherwise flowing in this branch. In making this adjustment on the a-c calculating board, it has been found convenient to have a stabilizing impedance in series with the source of electromotive force and to use a current transformer and ammeter for balancing the current $2I_{x1}$ in this source with the current I_{x1} in impedance $k-n$. When the adjustment is correct the ammeter reads zero.

A second form of equivalent circuit, the modified Π, may be derived by analogy with the modified T. This circuit, based upon eqs 17, is shown in Fig. 13. One branch has a series electromotive force which must be adjusted in phase and magnitude to $2E_{x1}$. A potential transformer and voltmeter connected as in Fig. 13 will facilitate the adjustment.

For double unbalances that are not symmetrical with respect to any phase, the mutual impedances, m and n in eqs 16, or the mutual admittances, $-q$ and $-r$ in eqs 17 are unequal, and the equivalent circuits of Figs. 12 and 13 are suitable. For double unbalances that do have a phase of symmetry, $m = n$ and $q = r$, and the equivalent circuits therefore reduce to a simple T or Π without a source of electromotive force.

The procedure for handling a double unbalance by the equivalent circuit method is as follows: The negative and zero sequence networks are set up successively and impedance measurements are made between points x, y, and g. From the results of these measurements the impedances of the branches of the equivalent circuit are computed. The positive sequence network then is set up, the equivalent circuit of the unbalance is connected to it at points x, y, and g, and its voltage, if any, is adjusted. Readings of current and voltage may then be taken throughout the positive sequence network, including points x and y. The negative sequence network then is set up, and voltages are applied from x to g and from y to g. Both applied voltages are adjusted in phase and magnitude until either the voltage or the current at each point is correct, according to a known relation between it and the positive sequence current or voltage measured at the corresponding point of the positive sequence network. (For example, in line-to-ground short circuits on phase a at x and on phase b at y, make $I_{x2} = I_{x1}$ and $I_{y2} = aI_{y1}$.) The zero sequence network is solved similarly.

Comparison of Connection Method and Equivalent Circuit Method. Suppose that a study of relay operation during simultaneous faults is being made on the calculating board, and that 4 or 5 circuit breakers must open in order to clear the faults. The first readings are taken with all breakers closed, and from these readings is determined which breaker will open first. Then the power system is represented with this breaker open and, from the readings taken under this condition and under the original condition, the second breaker to open is determined. The system is represented for the new condition, and so on until the complete sequence of relay and breaker operations has been found.

In using the connection method the 3 sequence networks are set up and connected together in an appropriate manner at each point of fault. The opening of each circuit breaker is represented by opening each of the sequence networks at the breaker location. No other change is necessary. In using the equivalent circuit method, however, it is necessary to measure the impedance of the negative and zero sequence networks from the points of fault, to calculate the impedances of the equivalent circuit, and to set up the equivalent circuit and adjust its voltage, if any. These steps must be repeated for each change of circuit connections or fault location.

Although the procedure of the equivalent circuit method is longer, the method has the advantages that the sequence networks can be solved separately, and that transformers and phase converters are not necessary. It is not a simple method to apply to multiple unbalances (unbalances connected to the balanced network at 3 or more points).

Accessories to the A-C Calculating Board

Transformers. The ideal transformers for use with the connection method would have both current ratio and voltage ratio exactly equal to unity—a requirement that cannot be fulfilled perfectly. However, transformers can be obtained that meet the conditions well enough to give reasonably accurate results. Transformers of 1 to 1 ratio are already standard equipment on some a-c calculating boards, being used for representing the mutual reactance of parallel transmission lines.

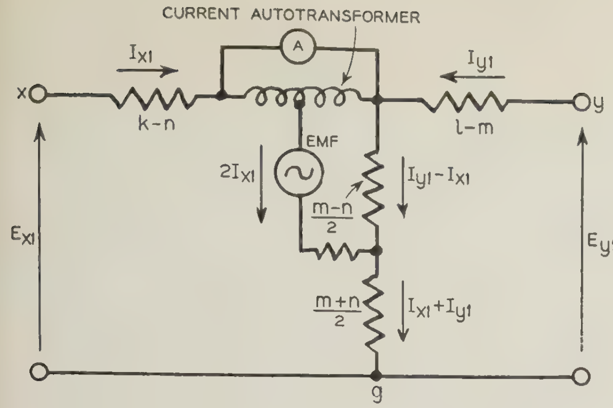


Fig. 12 (left). Modified T equivalent circuit to be connected to the positive sequence network for representing a double unbalance

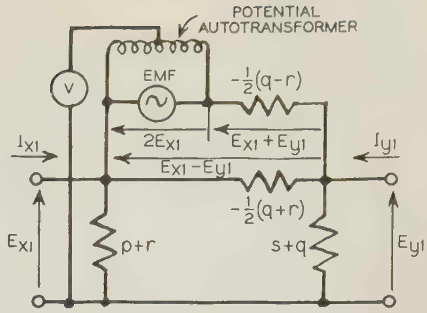


Fig. 13 (right). Modified π equivalent circuit

Phase Converters. The use of phase converters was suggested in the foregoing discussion of the application of the connection method to double unbalances having no phase of symmetry. The ideal phase converter for this purpose is one that will give a secondary voltage and current exactly equal in magnitude to, and 120 deg out of phase with, the primary voltage and current, respectively. Such a converter may be specified in terms of its impedance to currents of various phase sequences in this way: Its positive sequence impedance should be infinite, and its negative and zero sequence impedances should be zero. Suppose now that all 3 phase windings of such a converter be used instead of only 2, making it analogous to a 3-circuit transformer. The current and voltage relations of the ideal converter are then, denoting the 3 circuits as a, b, and c:

$$I_a + aI_b + a^2I_c = 0 \qquad E_a = aE_b = a^2E_c \tag{18}$$

Compare these with the corresponding relations for an ideal 3-circuit transformer or for 3 circuit branches in parallel:

$$I_a + I_b + I_c = 0 \qquad E_a = E_b = E_c \tag{19}$$

Suppose that another type of converter is desired giving current and voltage relations analogous to a series connection:

$$I_a = aI_b = a^2I_c \qquad E_a + aE_b + a^2E_c = 0 \tag{20}$$

The requirements for such a converter are that its negative and zero sequence impedances be infinite and that its positive sequence impedance be zero.

A 3-phase induction machine driven at or near synchronous speed roughly satisfies the requirements for either type of converter. Its zero sequence impedance may be made either zero or infinite by connecting the external circuits in Δ or Y, respectively. (The connection of the converter stator windings themselves is immaterial.) The positive sequence impedance of the machine is high and the negative sequence impedance low, or *vice versa*, depending on the direction of rotation. However, the induction phase converter is less "ideal" than a good transformer; and in its natural state its current and voltage ratios are not accurate enough for it to be of much practical use in connection with the calculating board. Its characteristics may be improved by (1) driving its somewhat above synchronous speed by another motor in order to annul its positive sequence resistance, and (2) connecting series and shunt capacitors in each phase to compensate for its reactance.

Negative Resistance Devices. In applying the equivalent circuit method to unsymmetrical double unbalances, usually one or more of the branches of the equivalent circuit are required to have negative impedances (that is, negative resistance and negative reactance). The negative reactance obviously can be furnished by capacitors, but negative resistance presents a problem. Several artifices can be used for representing it.

If the negative impedance is in the mutual branch of the equivalent circuit (that is, in the pillar of a T circuit or the architrave of a Π circuit) it may be replaced by an equal positive impedance, provided that one pair of terminals of the equivalent circuit be connected to the circuit through a transformer in such a way as to reverse the polarity of current and voltage at the terminals. This means is of no avail, however, for negative impedances in the other branches of the circuit.

The negative impedance in any branch may be replaced by an equal positive impedance shunted by an electromotive force which is adjusted in phase and magnitude until the current in the impedance is equal and opposite to the current in the main circuit;[6] or, the positive impedance may be n times as large as the desired negative impedance and the current in it $1/n$ as large. In either case the required voltage drop is introduced into the circuit. The adjustment of the electromotive force is facilitated by the use of a current transformer and ammeter, as described in connection with the modified T circuit. The principal objection to this means of obtaining a negative impedance is the necessity of adjustment—an adjustment not difficult in itself, but one that usually must be made simultaneously with the adjustment of other electromotive forces in the circuit. It would be preferable to have the adjustment made automatically.

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An Electronic Voltage Regulator

In this paper an effective means of controlling and regulating voltage with an external-grid rectifier tube is discussed. Four applications of the basic principles are shown, including a low voltage, wide range control, and a primary distribution voltage automatic regulator. Main features are: instantaneous response which enables this regulator to be used in such applications as welding with a pulse of only a few cycles, absence of heavy moving parts as well as absence of contacts for load currents, and low cost.

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A REGULATOR for maintaining constant voltage or constant current has been developed* which makes use of an electron tube to vary the voltage across an impedance in the circuit to be controlled. The tube is a grid controlled gaseous rectifier in which the grid is external to the tube. (For a description of this tube see "The Kathetron—A Controlled Rectifier" by P. H. Craig, *Electronics*, v. 6, March 1933, page 70–2.) It operates in a manner similar to other grid controlled rectifiers by inhibiting striking of the arc during the positive alternation of the anode potential, and after the arc has struck exerts no further influence upon it for the remainder of that half cycle. It can be used in practically any application where other grid controlled rectifiers may be used and in some applications has a considerable advantage over the other types due to the fact that the grid draws practically no current (being of the order of a few microamperes), and to other circuit advantages to be described.

In the fundamental voltage control circuit of the regulator, a reactor, or impedance in the form of a 2 winding transformer is used to reduce the load voltage by any desired amount, depending upon the effective value of the current through the grid controlled tube which is placed across this reactor or transformer. The primary of this transformer is connected in series with the circuit to be controlled while the secondary is connected across the anode and cathode of the tube. The tube varies the effective impedance of the reactor, which may have a winding ratio such that the tube is required to handle lower currents than exist in the primary of the circuit.

The action of this circuit is not the same as a saturable core reactor but involves rather the reflection of varying impedance from the tube back into the primary. The tube has a very high impedance when it is passing no current and a very low impedance after the arc has struck, so that its operation is similar to a short circuiting switch across the secondary of the impedance transformer. The time during which the tube is passing current, corresponding to the time during which the switch is closed, is varied by the action of the grid to inhibit the striking of the arc during the positive alternation of the anode potential. Thus, the tube cannot be thought of as a variable resistor in which heat losses must be dissipated, but rather as a switch which opens and closes, the time of remaining closed being variable.

Series Impedance Control

In the first application of this method a low voltage circuit is controlled directly to give reduction of voltage (see figure 1). Control of the circuit voltage is effected by varying the grid potential. Because of the negligible grid current the leads from the tube to the control point can be very small and the control can be from a considerable distance.

A similar circuit is used for a constant current supply, such as for street lighting circuits. A series reactor with a high voltage primary winding is used.

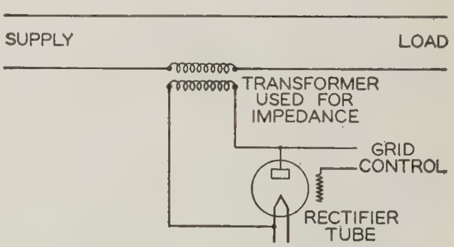

Fig. 1. Series impedance circuit for wide range control of voltage

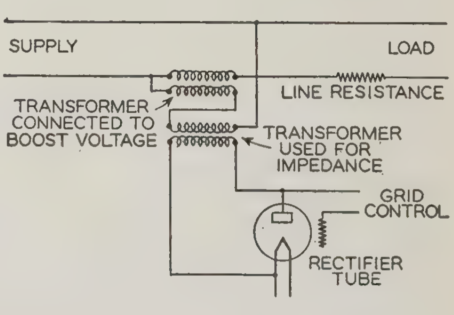

Fig. 2. Electron tube control of voltage boost for distribution line or industrial load

The grid control rheostat is adjusted by a small motor which is operated forward or reverse by the contacts of a current relay. Adjustment of this relay is such that a constant current of 6.6 amperes (or other desired value) is maintained in the primary

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* U. S. Patent No. 1,992,146.

circuit by varying the voltage on the output side of the reactor.

Controlled Boost Regulator

A most satisfactory method for regulation of primary distribution circuits is a controlled boost method. The reactor, or impedance transformer,

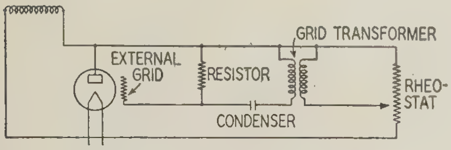


Fig. 3. Automatic grid control applied to impedance transformer secondary of voltage boost circuit shown in figure 2

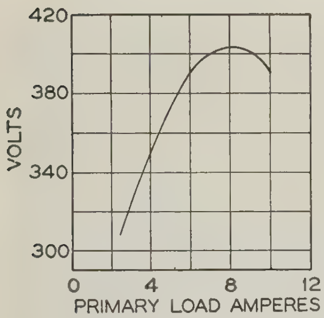
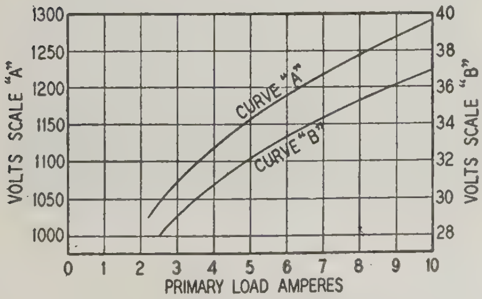


Fig. 4. Variation of voltage to primary of grid transformer to give perfect regulation (circuits of figures 2 and 3)

used in the 2 methods mentioned above is here placed in the primary or shunt circuit of a standard transformer connected for boosting the line voltage. The method then is to control the boost effect of the booster transformer by varying the voltage of its primary. A similar control circuit can be used for lower voltage circuits, such as power feeders of an industrial load, welding equipment, etc.

As in the constant current control, the voltage on the grid can be adjusted by a small motor driven mechanism. A standard contact-making voltmeter and a line drop compensator in the circuit to this motor control gives a boost control and, hence, a voltage regulation, to the load center of the primary feeder line. While this method gives an automatic control, with several operating advantages, the characteristics of the apparatus are such that an entirely static, automatic grid control can be used with very marked improvement in several features.

The static grid control can be obtained directly without the use of motor or contacts, by taking the grid supply from one of several points of variable voltage in the complete circuit. With one arrangement an increase of line current causes a decrease of grid voltage and thus causes a greater short-circuiting effect on the secondary of the impedance transformer. This in turn reflects less impedance back into the primary winding and allows more boost to offset the tendency of the load voltage to drop. In this application, the grid potential is taken directly from across the secondary of the impedance transformer. The primary connections of this control are shown in figure 2. A somewhat different control is obtained by connecting the grid circuit across the supply line either directly or from a potential transformer. A tendency for supply voltage to drop then produces a lower grid potential and, as in the other case, allows more boost to the output voltage.



Curve A (left scale). With tube not in circuit

Curve B (right scale). With tube in circuit but with zero grid voltage

Fig. 5. Voltage on secondary of impedance transformer

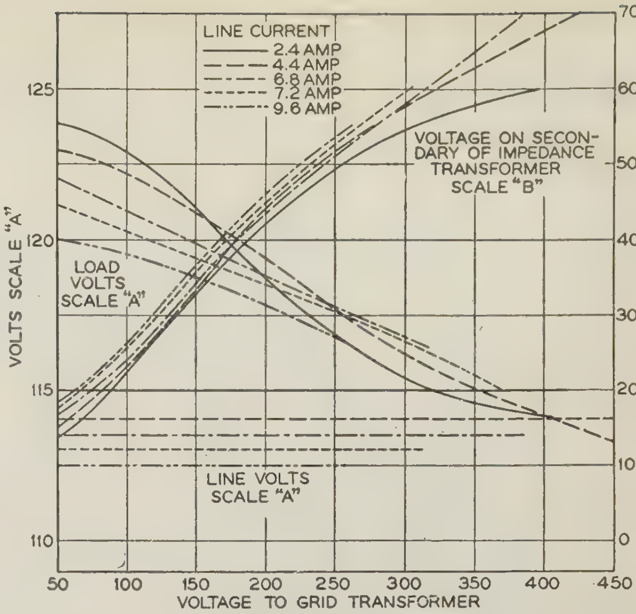


Fig. 6. Relation of impedance transformer and grid voltage for various values of line current. Regulator not operating

Operation of Tube Control

The tube control circuit of the controlled boost regulator with no moving parts is shown in figure 3. The potentiometer is connected directly across the anode-cathode of the tube (and of the secondary of the impedance transformer) and the grid voltage obtained from a portion of the potentiometer. The grid voltage necessary to maintain load voltage constant with a particular line condition (approximately 5 ohms) is shown in figure 4. These values were obtained with a manually controlled grid and they indicate the range necessary for automatic control. It was found that characteristics of the tube and impedance transformer circuit are such that a remarkably close approximation to the curve of figure 4 is obtained for the grid control.

The voltage across the secondary coil of the impedance transformer, without the tube control, is shown in curve *A*, figure 5, for increasing load current in the 2,400 volt line. With a half-wave mercury vapor rectifier tube in the circuit, the voltage as read

on ordinary a-c instruments, across the secondary of the impedance transformer, is shown in curve B, figure 5.

The slowly increasing voltage across the tube is due to the fact that all mercury vapor rectifier tubes when not controlled by a grid exhibit the characteristics of a constant voltage drop in the forward direction of current. However, the voltage read on ordinary a-c instruments across a single half-wave rectifier is a combination of the inverse voltage across the tube (i. e., the voltage across the tube during the negative alternation of the anode potential when the tube is passing no current) which may be quite high, and the forward potential drop during the half cycle in which the tube is passing current. Normally, the inverse voltage is very much larger than the forward potential drop, and consequently, what is read on the meter is largely inverse potential, unless special metering methods are used.

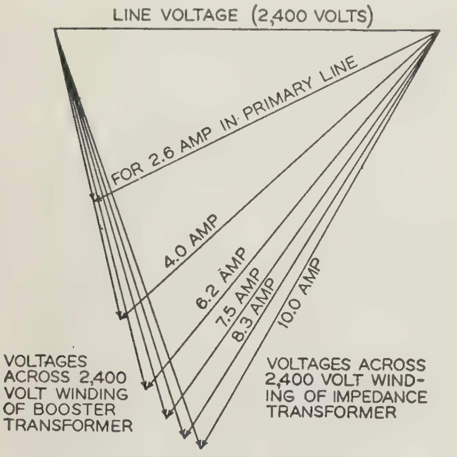


Fig. 7. Diagram of primary voltages with various load currents in primary line

Inasmuch as the tubes, even without a controlled grid, tend to maintain a constant voltage in the forward direction, they have an inherent regulatory characteristic since the only way that the tubes can have a constant drop maintained across them for higher current is to decrease their impedance. It is clear from the impedance transformer voltage characteristic that a higher voltage is impressed across the tube for higher load currents and, consequently, there is a larger current through the tube for increasing load. Therefore, for the tube to maintain constant voltage drop in the forward direction for increasing anode currents it must decrease its impedance so that the product of impedance and increasing current is a constant. This decreasing tube impedance for higher loads reflects a lower impedance back into the primary of the impedance transformer and thus allows more boost for increasing loads, which results in some degree of regulation. It is apparent that if 2 such tubes were employed, operating on different half cycles, some inherent regulation would be achieved without any grid at all or with a fixed value of grid potential, because in that case one tube would maintain a constant voltage drop in one half cycle and the other in the reverse.

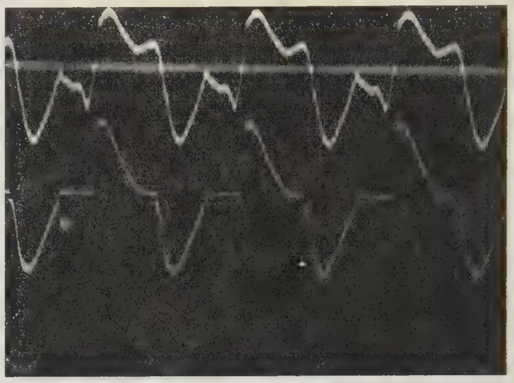
The rate of increase in the impedance voltage decreases for the higher value of grid voltage as shown in figure 6, giving an approximation to the shape of the curve in figure 5. Impedance voltage versus grid voltage curves were obtained by holding the line current constant and varying the grid voltage. As shown in curve B of figure 5 the voltage across the impedance transformer also is not linear and a combination of the 2 gives a still closer approximation to the curve of figure 4.

The phase angle of the booster transformer primary voltage remains almost fixed with respect to the line voltage, whereas the voltage across the impedance transformer primary varies considerably in phase with respect to the line voltage with changes in load current of fixed power factor. The vector relations are shown in figure 7 for several values of line cur-

Grid voltage

Tube voltage

Load voltage

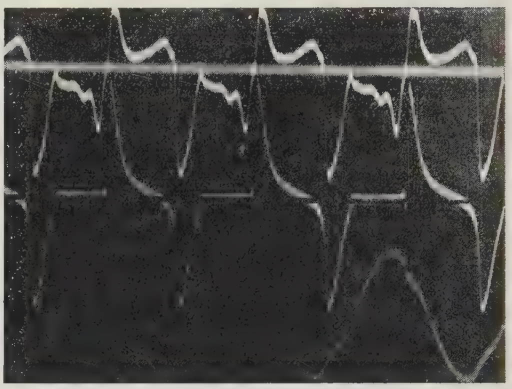


Load, 2.4 amperes in 2,400 volt line

Grid voltage

Load voltage

Tube voltage

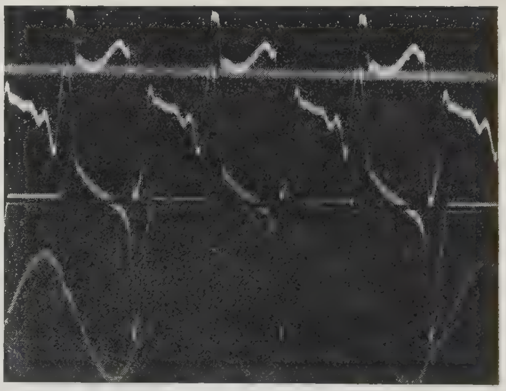


Load, 6.0 amperes in 2,400 volt line

Grid voltage

Tube voltage

Load voltage



Load, 9.8 amperes in 2,400 volt line

Fig. 8. Oscillograms of grid, tube, and load voltages during the operation of the automatic regulator

Table I—Load Test for Automatic (Static Type) Feeder Voltage Regulator

Load Amperes (in 2,400 volt line)	Load Voltage	Voltage Immediately Following Regulator	Watts Loss: Impedance Transf. Primary	Watts Loss: Impedance Transf. Sec. and Tube	Watts Loss: Booster Transf. Core	Watts Loss: Booster Transf. Copper	Watts Loss: Total	Kw Input	Kw Output	Efficiency % (neglecting grid losses)
2.3	121.0	123.0 × 20	62	40	10	2	114	6.02	5.91	98.1
3.0	121.5	123.5 × 20	60	30	17	3	110	7.78	7.67	98.6
4.2	121.5	124.0 × 20	80	40	24	5	149	10.81	10.66	98.6
5.3	121.5	124.5 × 20	70	30	28	7	135	13.62	13.49	99 0
6.6	121.0	124.7 × 20	80	20	31	10	141	16.94	16.8	99.2
8.45	120.0	124.3 × 20	100	37	33	17	187	21.45	21.26	99.1
9.8	119.5	124.5 × 20	90	30	34	22	168	24.85	24.68	99.3

rent. Since the voltage across the primary winding of the impedance transformer is not a sine wave, it is not possible to represent accurately the operation of the circuit by a vector diagram. However, the apparent vector relations as shown in figure 7 serve to indicate why it is possible to obtain increasing voltage across both the primary winding of the booster transformer and the primary winding of the impedance transformer, while the line voltage remains substantially constant.

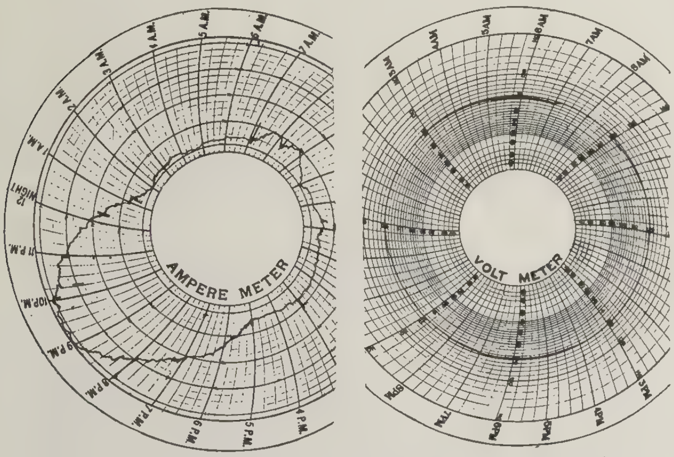


Fig. 9. Graphic charts for current and voltage (at load center) on a typical suburban type feeder regulated with the electron tube regulator

Although the current varied between 1 and more than 5 amperes, the voltage is shown to vary only between 120 and 118 volts. Without regulation the voltage dropped 8 volts with the same load variation

The tubes are used commercially well under rating so that their life is increased. It is a general characteristic of such tubes that they will stand tremendous overloads for short periods of time. This point is important in considering the short-circuit capacity of regulators using this type of tube. These tubes will stand 25 times normal current for very brief periods, and are usually equipped with a slow acting fuse which will not operate in the case of a line short circuit unless the ordinary line protection fails. In the event of tube failure or opening of the tube fuse, service is not interrupted, but there occurs only a drop in line voltage equal to the percentage boost at that time. A relay could be provided which would short-circuit the impedance transformer and supply full boost in the event of tube failure, but the condition of lowered voltage is usually thought better.

Table II—Test Results for Voltage Regulator With Mechanically Operated Grid Control

Amperes: Load in Primary Line	Voltage: Supply (20/1)	Voltage: Load	Power Factor: Input %	Power Factor: Load %
2.4	123	120.5	91	90
6.8	121	120.3	97	95
11.2	119	119	98	96
13.6	118.5	119	96	98
16.0	117.5	119.5	97	100
18.4	117	119.2	99	100

Results With Controlled Boost

The oscillograms of figure 8 show the grid voltage, tube voltage, and load voltage on an experimental 2,400 volt line having about 5 ohms resistance to load center. The regulation at the load, on the secondary of a 2,400/120 volt distribution transformer, was within 2 volts at all times. In this set-up the grid controlled circuit of the tube and the filament transformer were immersed in oil. The slight distortion in output wave-form is generally not sufficient to produce any appreciable detrimental effect as regards motor core losses and the like. Relatively simple filters have been devised which seem to eliminate any undesirable telephone and radio inter-

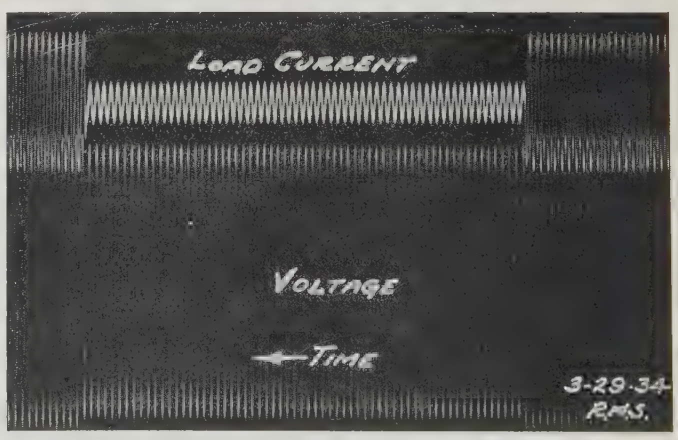


Fig. 10. This electron tube regulator gives voltage increase within same half cycle that current increases

ference due to the presence of harmonics, as it can be seen from the oscillograms that these harmonics are small in magnitude. The data for a load test are given in table I. Tables II and III give load test results for the mechanically controlled grid circuits, when applied to constant voltage and to constant current control, respectively.

In figure 9 are shown graphic charts for current and voltage (at load center) of a typical 24 hour run on a suburban type feeder regulated by the automatic arrangement of figures 2 and 3. The resistance of the line from regulator to load center was approximately 5 ohms.

One of the most outstanding characteristics of the automatic tube regulator is its instantaneous response in control during changes of load, as shown in the oscillogram of figure 10. The regulator responds during the same half cycle to give an increase of voltage at the load with the increase in current.

Summary

The use of tube controlled regulators offers a number of advantages which warrant careful consideration. The absence of heavy moving parts is one of the outstanding features.

The instantaneous response of the controlled boost regulator described here is a very important point in consideration of short duration loads, such as welding. With the ordinary type of regulator these loads cause a continual pumping effect as the regulator is not able to keep up with the rapidly changing load conditions.

Table III—Test Results for Constant Current Regulator With Mechanically Operated Grid Control

Load			Power Factor		
Amperes	Volts (20/1)	Kw	Input %	Load %	Efficiency %
6.65	36	4.6	37.7	95.5	76.5
6.6	45.5	5.6	44.3	93.0	80.0
6.55	54	6.6	51.5	93.0	81.5
6.5	65	8.0	60.5	94.5	85.2
6.4	79	9.6	72.0	95.0	87.2
6.65	95	11.7	81.7	92.5	90.0
6.6	106	12.8	90.0	91.5	90.2

Because of the low cost of tube control, this type of regulator may be found economical for installations on individual industrial or commercial loads where other means of regulation are found too expensive, or where, because of the rapid fluctuation of the load, the other types of regulators may be ineffective.

Tube replacement, particularly on rural distribution lines, is worthy of consideration. However, the life of indirectly heated tubes of this type is of the order of several thousand operating hours. On this basis an annual inspection and changing of these low priced tubes should be all that is necessary. In any case the failure of a tube does not mean interruption of service, but would be noticed by the absence of regulation on the circuit.

Oil Circuit Breaker and Voltage Recovery Tests

A series of tests on a circuit breaker of the oil blast type was conducted at the Richmond station of the Philadelphia Electric Company. Particular attention was given to the rate of recovery of voltage following the actual interruption of the circuit. Unusual details in the operation of the cathode ray oscillograph also were worked out. These, and other features of the tests, are described in detail in this paper.

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IN VIEW of the high recovery voltage rate calculated for certain circuit locations where circuit breakers were to be installed in the Richmond station of the Philadelphia Electric Company, this company decided to make interrupting capacity tests on the circuit breakers in the field for the 2 purposes of determining the breaker performance and verifying calculations of the recovery characteristics. (The recovery voltage rate of an a-c power circuit is the term given to the rate, in volts per microsecond, at which the voltage rises across the terminals of a circuit breaker immediately following the interruption of current by that breaker.)

It is the purpose of this paper to record these tests with special notes on the recovery voltage phenomena and their calculation and on the theory and performance of a novel method of initiating the operation of a cathode ray oscillograph for their measurement. Comparisons are given between calculated recovery voltage curves and cathode ray oscillograms and between the recovery rates determined from these curves and oscillograms.

Due to the fact that all the equipment was not yet installed at the time the tests were made, it was impossible to make the tests under the exact conditions of the final installation. For the tests, the circuit breaker was therefore set up in a temporary

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shelter outside the building, and temporary buses were run to it. Recovery rate calculations were made both for the final installation and for the test set-up and particular pains were taken to make the test as severe in this respect as the final installation.

The following conclusions may be drawn from the material presented in this paper:

1. The oil-blast circuit breaker is so uniform as regards arc length that the time of interruption can be indicated within one half cycle by an auxiliary contact attached to the operating rod.

2. A properly designed saturated-core current transformer may be used to supply a voltage impulse for the purpose of initiating the record of the cathode ray oscillograph a short time before the current zero.

3. A reasonably accurate estimate of the recovery voltage rate was obtained by calculation.

4. The circuit breaker appears capable of performing satisfactorily under the worst recovery rate conditions to be encountered in the installation.

The Circuit Breaker

The circuit breaker was a type *FHK*-330-32*B*, rated 15,000 volts, 5,000 amperes, and 1,500,000 kva interrupting capacity. This is an indoor circuit breaker with 32 inch diameter round tanks, one for each phase, down break, and explosion chambers. A photograph of it, mounted on the test frame, is shown in figure 1. It should be noted that in the final installation, an isolated phase arrangement is to be used with the 3 phases on different floors, so that the mounting of the circuit breaker would be quite different.

A view of the circuit breaker with the tanks down is shown in figure 2. Here may be observed the explosion chambers and the massive contacts required for carrying the high continuous current for which the breaker is rated. A detailed view of the blades for carrying the continuous current is shown in figure 13.

A view of the interior of the explosion chamber is shown in figure 10. The chamber has a throat bushing with a vertical center hole through which the contact rod moves and the arc is drawn, and in addition, a horizontal hole passing directly across the vertical hole and communicating at one end with the oil pocket and arcing space at the top of the throat bushing, and at the other end with the oil in the tank outside the explosion chamber. Metal gates are mounted on the throat bushing in such a way as to close off the top of the vertical hole when the contact rod is not in the closed position. At the top of the explosion chamber is mounted a female contact of the conventional segment type with a metal bell immediately below to protect the segments from the arc.

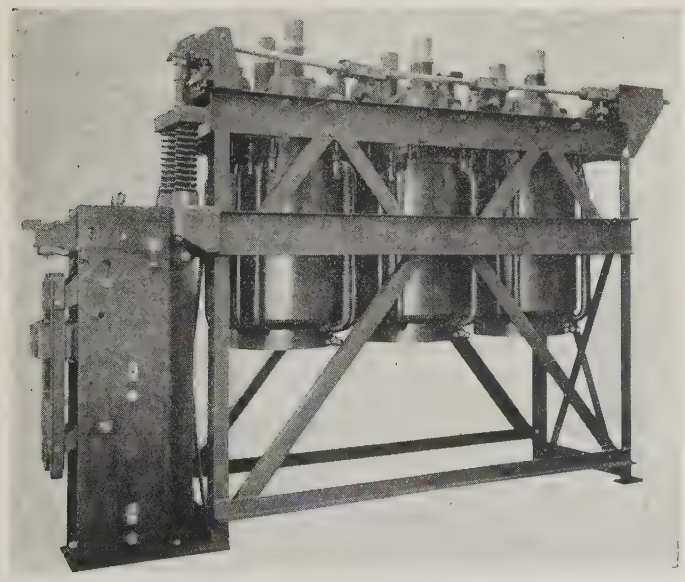

Fig. 1. Oil circuit breaker, type FHK-330-32B, 15,000 volts, 5,000 amperes, mounted as for the tests

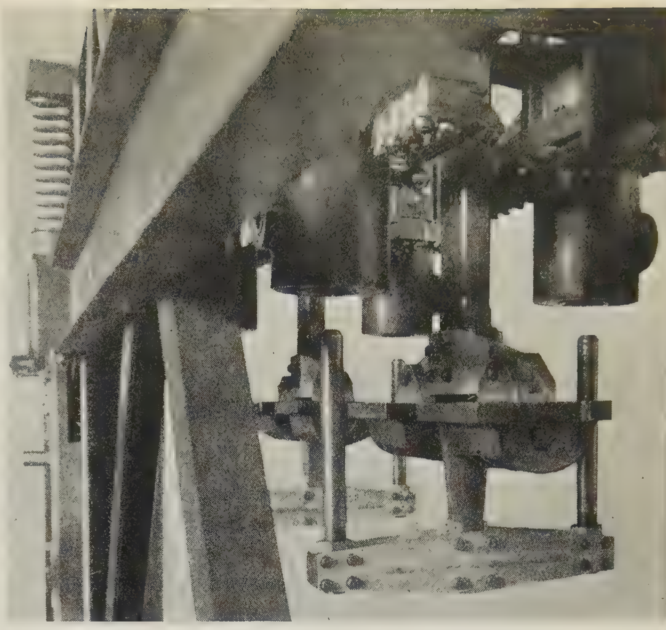

Fig. 2. Test oil circuit breaker with tanks lowered

The operation of this chamber is as follows:

On closing, the contact rod pushes up through the center hole of the throat bushing, opens the gates, and finally enters the female contact at the top of the explosion chamber, completing the circuit. After the contact rod has entered the female contact far enough to assure a good contact, a parallel circuit is completed through the main contacts outside the explosion chamber.

On opening, the circuit through the main contacts is broken while there is still a good contact in the explosion chamber, transferring the current to these contacts. The contact rod then pulls out of the segments and down through the throat bushing, and the gates close behind it. This divides the arc into 2 parts, one about $^3/_4$ inch long between the gates and the arcing bell above, and the other in the throat bushing between the gates and the contact rod. The upper arc generates pressure which forces oil out through the horizontal hole and thus across the lower arc, which is thereby extinguished.

Arrangement of the System; and Recovery Voltage Calculations

A. In the Final Installation. Richmond station is of the isolated phase type, with the switching and protective equipment of the different phases on different floor levels. As is usual in large metro-

politan stations, each generator, tie line, or other connection to the main bus has its own reactor and a circuit breaker corresponding to each bus. These reactors, of course, serve the intended purpose of limiting the short-circuit current, but they also make for high natural frequencies of oscillation of the power circuit when the electrostatic capacitance of the bus-work is small. In this station all the buses are of the open type, with consequent low capacitance.

In the final installation the 15,000 volt, 5,000 ampere circuit breakers are generator breakers, situated between the main bus and the 0.087 ohm generator reactors, which are in turn connected to the 183,333-kva double-winding generator. The system diagram, with reactance values given on a 100,000 kva base, is shown in figure 3. In making up this diagram, no attempt has been made to segregate the reactances outside of the ring bus according to their nature. The reactances are divided in all cases into 2 parts: the reactance appearing before a large capacitance is reached, and the remainder of the reactance of the circuit.

For the circuit breaker in question, ruling out the improbable case of a short circuit between breaker and generator reactor, a 3-phase ungrounded fault between the 183,333 kva generator and its reactor gives the most severe fault with respect to both current and rate of rise of recovery voltage. Using the values given in figure 3 the system reduces to that shown in figure 4. In simplifying the circuit for a recovery rate calculation it is necessary to preserve with at least moderate accuracy the distribution of reactance and capacitance of the system. The capacitance C_1 is that of the bus and connected bushings between the circuit breaker and the generator reactor L_1; C_f is the capacitance of the short-circuit point, including that of the generator; C_2 is the capacitance of the main bus and its connected bushings, and L_2 is the parallel reactance of the reactors between the bus and points of large

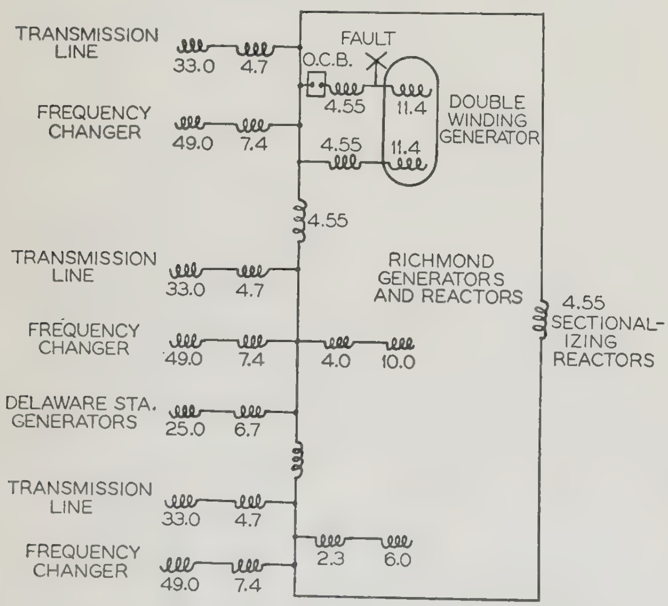

Fig. 3. Reactance diagram of Richmond station and connected apparatus

Reactance values are given on a 100,000 kva base

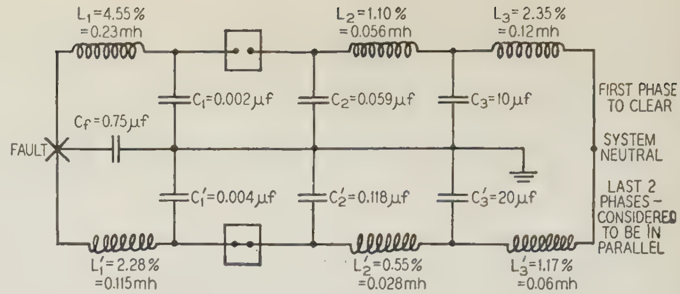

Fig. 4. Simplification of figure 3 as required for solving for recovery rates

μf—microfarad   mh—millihenry

capacitance, such as long cables and generators. C_3 is the capacitance of these cables and generators, while L_3 is the remaining system reactance. C_3 and C_f are very large compared to C_1 and C_2, while the reactances are all of the same order of magnitude, so that C_3 may be considered as a short circuit as regards the oscillation of L_2 and C_2, and C_f similarly as regards the oscillation of L_1 and C_1.

The only high oscillating frequencies are those of L_1C_1 and L_2C_2 which are 234,000 and 88,000 cycles, respectively. The fractions of system voltage associated with these frequencies are as L_1 and L_2 to the total reactance, L_0. For a double frequency oscillation, the rate of rise of recovery voltage is given very closely by the expression

$$r = k_g k_q k_\delta e \delta\, 10^{-6} \frac{f_1}{L_0}\left[4.55L_1 + 2.85L_2\left(1-\cos\left(\frac{f_2}{f_1}\times 133 \text{ degrees}\right)\right)\right]$$

where

r = recovery rate, volts per microsecond
k_g = ground connection factor
= 1.5 for a 3-phase ungrounded fault
k_q = quadrature reactance factor = 1.0 (approximately)
k_δ = ratio of voltage at inception of short circuit to voltage at the time of interruption
= 1.0, assumed momentarily
e = peak leg voltage
δ = high frequency decrement, assumed 0.95 from inspection of previous cathode ray oscillograms
f_1 = higher oscillating frequency of L_1 and C_1
f_2 = lower oscillating frequency of L_2 and C_2

Substituting values into the equation

$$r = 1.5\times1.0\times1.0\times\frac{13{,}800}{\sqrt{3}}\times\sqrt{2}\times0.95\times10^{-6}\times\frac{234{,}000}{12.00}\times$$
$$\left[4.55\times4.55+2.85\times1.10\left(1-\cos\left(\frac{88{,}000}{234{,}000}\times 133\text{ degrees}\right)\right)\right]$$
$$= 6{,}800 \text{ volts per microsecond}$$

This recovery rate is the maximum possible, and assumes no d-c component of short-circuit current and no decay of flux in the generators. For interruption in 8 cycles, the decrement would lie between 0.85 and 0.90, giving a recovery rate of 5,800 to 6,100 volts per microsecond.

B. In the Test Set-Up. As mentioned previously, the circuit breaker under test was placed in a temporary enclosure, with cambric-covered cables connecting it to the station bus-work. The use of lead cables was avoided so as to keep to a minimum the capacitance to ground of the leads. The circuit breaker neutral was ungrounded since this gives a higher recovery rate than otherwise.

The tests were made in 3 groups, each comprising

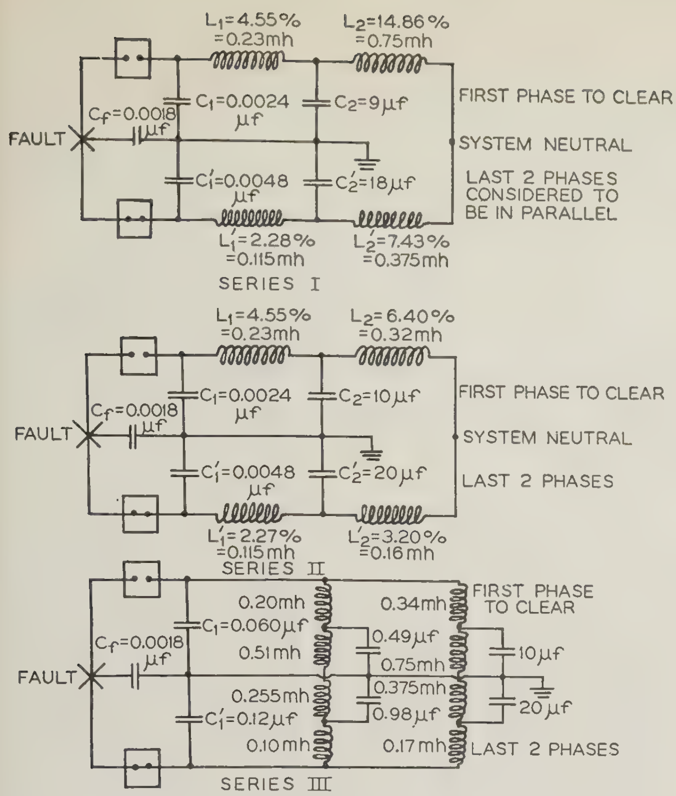

Fig. 5. Simplified diagrams of the 3 test set-ups

µf—microfarad mh—millihenry

CO and OCO operations. (A *CO* operation is one in which the short circuit is thrown on outside the circuit breaker while the breaker is in the closed position and the breaker has only the duty of opening the circuit. In an *OCO* operation, the circuit breaker closes upon the short circuit and then opens immediately.) First, preliminary tests of approximately 260,000 kva were made, utilizing only generators at Delaware station, connected to Richmond station by the tie cables, and with the 4.55 per cent reactor connected between the bus and the test breaker. Next, all the Richmond generators available for test purposes were added to the bus, and as in the first series the fault was applied through the 4.55 per cent reactor. In the last series the full available generating capacity was applied to the circuit breaker, with the 4.55 per cent reactor short-circuited.

The circuit constants for the 3 series are given in figure 5. The recovery rates calculated from these constants will be found in table II, column 4.

In order to insure the recording of the recovery characteristic of the first phase to clear, which was expected to have the highest recovery rate, the contact rods of the *C* phase, to which the cathode ray oscillograph was connected, were made one inch shorter than the contact rods of the other 2 phases. This was sufficient to cause this phase to clear first in every case.

Determination of Recovery Characteristic From the Oscillogram

These tests exemplify a type of modification of the inherent recovery voltage characteristic of the circuit caused by the circuit breaker that to date has received little discussion. Where the recovery voltage characteristic consists of a single oscillation at a given frequency, the effect of arc voltage will be simply to increase the amplitude of oscillation by a fraction never greater than the ratio of arc voltage to normal peak voltage. This will cause an increase in recovery rate which will usually be quite small.

If the characteristic is a combination of 2 or more oscillations at widely different frequencies, however, the result may be quite different. In this case, if there is no arc voltage, the higher frequency oscillation starts from zero; but if there is appreciable arc voltage, the higher frequency oscillation starts from a negative value equal to the arc voltage. If the higher frequency oscillation has less than half the total amplitude, this results in a reduction in the positive voltage of the first peak of the high frequency oscillation and a corresponding reduction in recovery rate, the latter being defined as the steepest tangent to the voltage curve from the zero of voltage and time. This reduction may be considerable, and is so in the present case, even without very high values of arc voltage.

In a given test, the recovery rate may be influenced by the following factors in addition to that just mentioned:

a. Displacement of the current wave.

b. Decrement of the a-c component of current.

c. Conduction of a small amount of current by the circuit breaker for a very short time after the last normal current zero.

In these tests, the effect of the first and third items above was negligible in most cases. The decrement reduced the amplitude of the characteristic by about 15 per cent.

The combined effect of decrement and arc voltage is illustrated in figure 14 by the 2 calculated curves corresponding to connection number 2 of the tests. Here the dotted curve corresponds to the ideal condition and, in the case of the solid curve, an arc

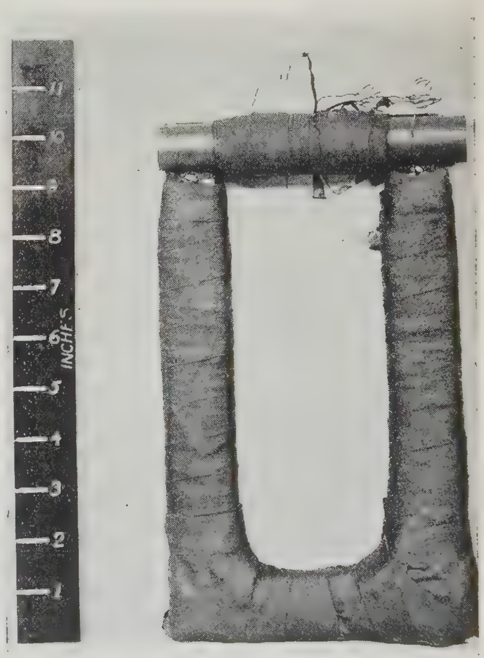

Fig. 6. Current transformer used for precise timing

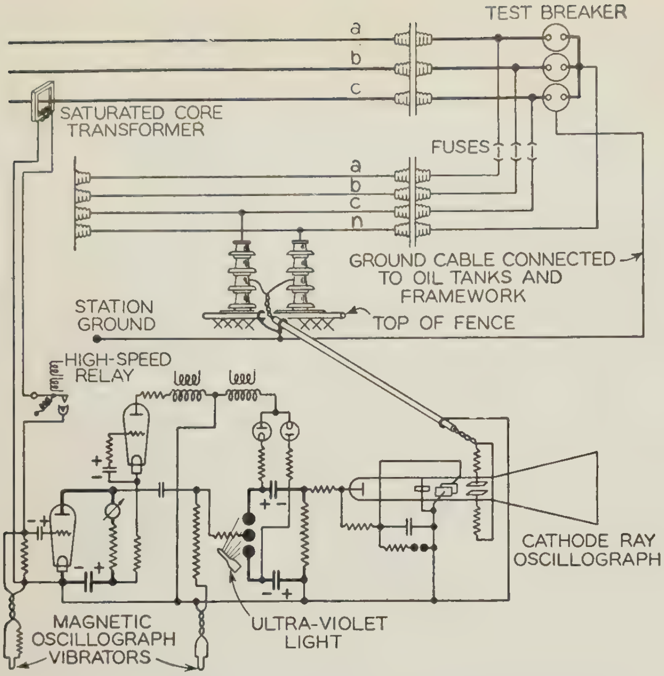

Fig. 7. Diagram of cathode ray oscillograph circuit

Switch settings
For all tests: Close I; reset high speed relay lifting lever by hand
CO tests: Close relay contacts; close III
OCO tests: Open relay contacts; close II and III

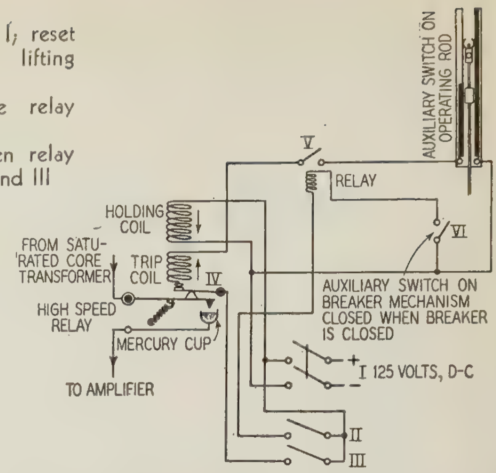

Fig. 8. Details of timing for cathode ray oscillograph

voltage of about 6 kv, together with the generator flux decay, reduces the positive voltage of the first peak from 13 kv to 8 kv, resulting in a reduction of recovery rate from 6,600 volts per microsecond to 4,500 volts per microsecond.

In table II are given the recovery rate values as measured directly from the oscillograms (column 2) and the inherent rates for the system as determined by correction of the above values for arc voltage and current decrement (column 3). The latter values are comparable to the calculated figures in column 4.

Method of Timing the Oscillograph

A. Schemes Previously Used. Several schemes have previously been used for synchronizing the cathode ray oscillograph record with the recovery voltage phenomena. The most obvious method is to use the recovery voltage surge itself to break down a 3-electrode gap, thereby completing a circuit which places voltage on the cathode. This method was used for the first recovery voltage records obtained by the company with which the authors are associated.

With the ordinary characteristic, this gives a satisfactory record of the recovery voltage build-up. Furthermore, in the case of 3-phase tests without very high recovery voltage frequencies, it has been made to trip occasionally on the current zero of another phase 60 degrees before the clearing of the phase to which the measuring plates were connected. Thus a record of the arc voltage for several milliseconds before current zero was obtained, as well as several milliseconds of the recovery voltage.[1] For the present case, however, the existence of a 200,000 cycle oscillation involving only a part of the recovery voltage ruled out tripping as much as 60 degrees early, and at the same time made it appear very doubtful that the above scheme could be made sufficiently sensitive to obtain the early part of the record without a serious risk of losing the record entirely through tripping at an early current zero.

Some investigators[2] have used a revolving drum, recording for several cycles at normal system frequency. This has a number of advantages in that it not only records the arc voltage immediately before current zero, but also gives a record of several current zeros for the same test; but it was quite out of the question for the present application as, in order to extend one cycle of the highest frequency oscillation over 0.1 inch, a film speed in excess of the peripheral speed of turbine buckets would be required.

A mechanical contact-making device has also been attached to a synchronous machine on the power system supplying the short-circuit current.[3] This permits precise and reliable synchronization with

1. For all numbered references, see list at end of paper.

Table I—Circuit and Breaker Performance

Test Group No.	Circuit Condition	Number of Tests	Average R. M. S. Current: First Cycle	Average R. M. S. Current: Initial in Arc	Time from Trip Impulse to Interruption—Cycles	Arc Length*: Cycles	Arc Length*: Inches per Break
1	Power only over cables from Delaware station. Reactor in circuit at Richmond	5	13,800	10,800	8	1.0	1.6
2	Power from Delaware station and from all available generators at Richmond. Reactor in circuit at Richmond	4	26,000	18,100	8	1.0	1.6
2a	Same as 2	4	24,000	19,500	8	0.7	1.3
3	Power from Delaware and Richmond. Reactor removed from circuit	4	31,000	24,000	8	1.0	1.7

* Measured from bottom of gates.

the current zero after the d-c component of short circuit current has died away, but before that time it is useless. Furthermore, this scheme is just as likely to operate on any current zero as on any other and, therefore, without some auxiliary means of selecting the correct current zero, it could not be applied successfully.

B. The Scheme Selected. The scheme selected required auxiliary means of selecting the correct current zero, just as in the scheme of the previous paragraph. This selection was made possible by one of the salient features of oil-blast circuit breakers; the short and consistent arc lengths. Preliminary tests in Schenectady indicated that there was but a very slight probability of failure to interrupt the circuit on the first current zero after a gap of $^3/_4$ inch was established between the moving contact tip and the bottom of the gates, and likewise there was not a very great probability that the breaker would clear before that time. Hence, a relay closing at the time when a $^3/_4$ inch gap was established would select the correct current zero with a fairly high degree of reliability. A relay was made to close at this time by connecting an auxiliary contact, outside the circuit breaker, directly to the wooden operating rod of one pole by means of a small steel rod passing through the top of the circuit breaker. This contact operated a high speed relay situated close to the cathode ray oscillograph and electrically in the tripping circuit for this oscillograph. The auxiliary contact was set ahead far enough to allow for the time required to close the contacts of the high speed relay. The allowance made was correct on CO tests, but the opening speed of the breaker was somewhat lower on OCO tests, and in a number of cases this threw the timing out. The contacts of the high speed relay were of special design in order to eliminate any possibility of bouncing contacts breaking the circuit on the closing stroke; they consisted of a pin and a pool of mercury.

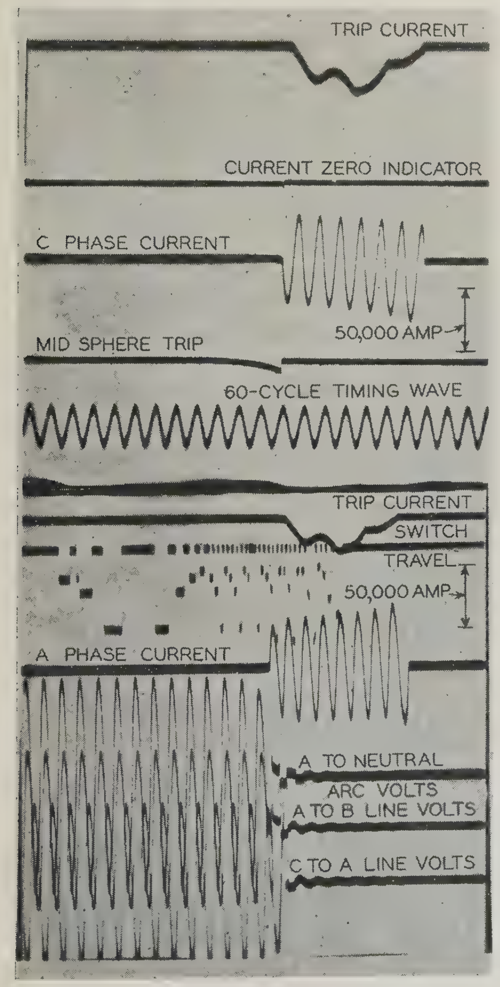

Fig. 9. Two oscillograms from one test of group number 3

The second unit of the timing system had the function of predicting with precision the time of occurrence of the selected current zero. It consisted of a substantially open-circuited current transformer (see figure 6) with a single-turn primary winding formed by a short section of the conductor feeding the pole of the breaker to which the cathode ray oscillograph deflection plates were connected. The core was a rectangular frame of high grade 0.014 inch iron with a cross section of 0.28 square inch, a mean length of 27 inches, 2 interwoven and 2 butt joints. The secondary winding had 50 turns and was connected in series with the contacts of the high speed relay to the grid of a 3 electrode vacuum amplifying tube, whose output voltage was fed to the mid-sphere of a 3 electrode gap.

C. Anticipated Performance. During that part of the cycle in which the primary current was high, it was anticipated that the core of this transformer would be saturated. Hence, although the primary current might be changing at a high rate, the flux in the core would remain practically constant and there would be no secondary voltage. When the current decreased, however, to a value insufficient to maintain saturation in the iron, the flux would begin to decrease very rapidly, and a comparatively high voltage would be induced in the secondary winding. Time was not available before the tests to obtain any experimental data on the shape of the hysteresis loop for such high values of magnetization as would be encountered, but a study of such curves as were available indicated that the following assumptions might be sufficiently accurate for a preliminary estimate of performance:

1. The magnetization curve might be considered a straight line from zero up to 80,000 lines per square inch at 10 ampere turns per inch and any increase in flux density beyond 80,000 might be neglected.

2. A 5 mil air gap appeared sufficient to reduce the residual magnetization to about 16,000 lines per square inch so that 40 per cent of the flux change from positive maximum to negative maximum would appear before current zero.

On the basis of these assumptions, it was estimated that a voltage surge would appear at a time of the order of 50 microseconds before current zero. In the

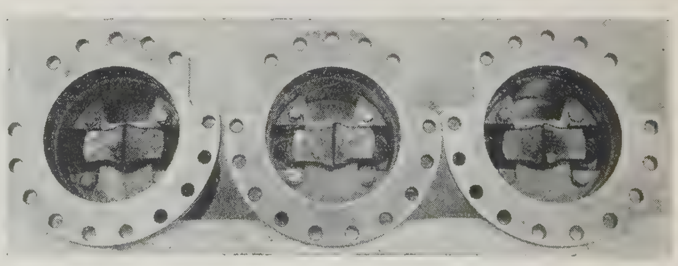

Fig. 10 (right). Top view of 3 explosion chambers after tests

Gates shown were in use for test group number 3 only

actual construction, no air gap was inserted, as it was anticipated that the 2 butt joints would be roughly equivalent to a 5 mil gap.

With the specification that one cycle of a 200,000 cycle oscillation shall be spread over 0.1 inch, a sweep speed of 20,000 inches per second is required, and the available record length of 4.5 inches would be covered in 225 microseconds. Tripping about 50 microseconds before current zero gives a good location of the current zero on a record of this length. It was found when this arrangement was tested that in the case of the higher currents there was a sufficiently rapid change in flux linkages above the density of 80,000 lines per square inch to cause earlier tripping than was anticipated. Thus with currents of about 10,000 amperes, tripping occurred at about the anticipated point. At 20,000 amperes, however, tripping occurred about 100 microseconds before current zero and at the highest currents, considerably earlier. A longer sweep was desired for the highest current tests, however, so this performance was considered satisfactory.

The wiring diagram for the complete circuit is shown in figure 7 and the details of the circuit for current zero selection in figure 8.

The use of an amplifying circuit was dictated not so much by inability to generate sufficient voltage in the current transformer to trip the 3 electrode gap as by the inconvenience of handling on a high speed relay not only the 3 or 4 kv necessary for tripping, but also the 25 kv which would be present on the mid-sphere during the operation of the cathode ray oscillograph.

The performance of the various elements of the cathode ray oscillograph circuit can be traced in the second oscillogram of figure 9. Here a slight discontinuity on the "current zero indicator" record just before the end of the last half cycle of short-circuit current indicates the closing of the high speed relay, a sharp surge on the record very soon afterward shows the reaction of this circuit to the current zero, and a disturbance in the "mid-sphere-trip" record indicates that the sphere gap broke down, initiating the operation of the cathode ray oscillograph, at the same time.

Fig. 11. Contact rod tips after test group number 3

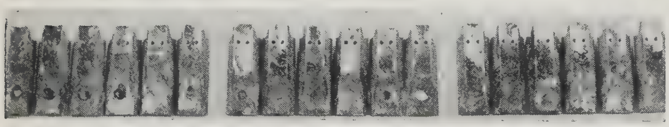

Fig. 12. Segments from female contacts of 3 explosion chambers after tests

Table II—Recovery Rates

Connection Number	Recovery Rate Measured From Cathode Ray Oscillogram	System Recovery Rate Determined by Correction of Cathode Ray Oscillogram	Calculated Recovery Rate of System	Approx. Short-Circuit Kva
1	1,500	4,600	3,700	270,000
2	3,800	5,600	6,600	500,000
3	1,050	1,600	1,200	600,000

Results

A. Circuit and Breaker Performance. The circuit and breaker performance, except for recovery rates, is summarized in table I. At the conclusion of test group number 2*a*, the tanks were lowered for inspection of the contacts. Approximately $^3/_8$ inch was burned from the contact rod tips, and the gates were burned moderately but were still serviceable. New contact tips and gates were installed and the segments of the female contacts were smoothed up slightly.

Two of the 3 oscillograms from one test of group number 3 are shown in figure 9. After group number 3, the contact tips were burned away about $^1/_4$ inch. The gates were again moderately burned, but still serviceable.

Figures 10 to 13 show, respectively, a top view of 3 of the explosion chambers, the contact rod tips, segments from 3 of the female contacts, and the blades of the current carrying contacts after test group number 3.

B. Comparison of Calculated and Measured Recovery Characteristics. The recovery rates as calculated and as obtained from the cathode ray oscillograms are given in table II. The calculated characteristics are plotted, also, and shown beside the oscillograms in figure 14. The agreement between the calculated and measured values is reasonably good, except in the case of connection number 3, which was not considered of great importance because of the comparatively low recovery rate, and which was a very difficult circuit to calculate because of the difficulty of estimating correctly all the elements of bus capacitance.

The frequencies of the various oscillations as given by the cathode ray oscillograms and by calculation are shown for the purpose of comparison in table III.

C. Timing of the Cathode Ray Oscillograph. On the CO tests, the selection of the correct current zero was achieved with success most surprising to

Table III—Oscillating Frequencies

	Highest	Second	Third	Fourth
Connection number 1				
By cathode ray oscillograms	190,000	160,000	*	
By calculation	220,000	190,000	2,000	
Connection number 2				
By cathode ray oscillograms	190,000	160,000	2,700	
By calculation	220,000	190,000	2,700	
Connection number 3				
By cathode ray oscillograms	190,000†	75,000	28,000	2,400
By calculation		59,000	14,000	2,400

* Record not long enough to determine frequency.
† Extremely low amplitude.

Fig. 13. Blades for carrying continuous current after tests

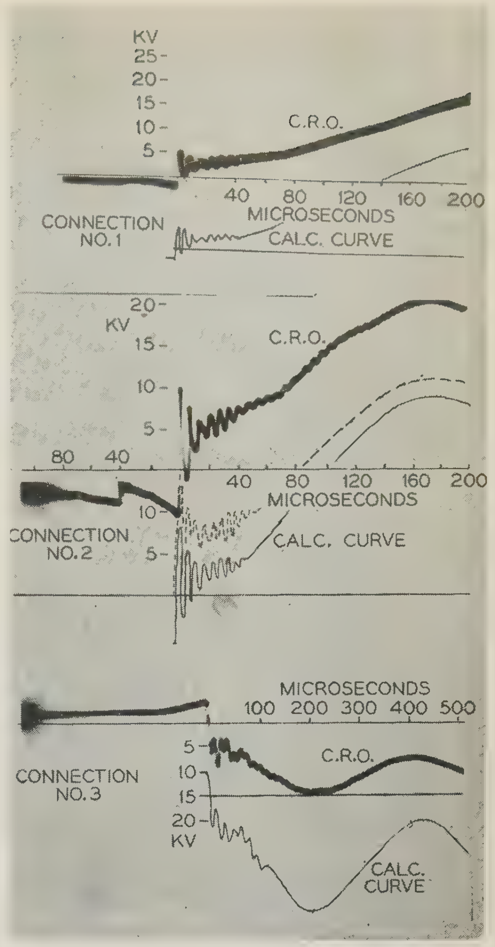

Fig. 14. Cathode ray oscillograms and calculated recovery voltage characteristics for the 3 connections

The dotted curve in the connection number 2 diagram is the calculated curve without allowance for flux decay or arc voltage

one familiar with the inconsistencies in arc length associated with circuit breakers of the past. On the OCO tests, sufficient allowance was not made for the lower opening speed of the breaker, with the result that the timing, while just about as consistent as on the CO tests, was a half-cycle early in most cases.

There were, likewise, very few irregularities in the precision timing, the current zero occurring in most cases slightly before the mid-point of the record.

The results obtained in the timing of the cathode ray oscillograph, with CO and OCO tests segregated, are summarized by table IV.

Comments

The currents obtained in groups 2, 2*a*, and 3 were considerably less than anticipated. Subsequent measurements of the reactance from bus to short-circuit point and calibration of the current transformers at high current account for a part of the difference, but there remains a discrepancy of about 20 per cent which is apparently attributable to the use of conservative values of alternator reactance. Designers of turbine-alternators have been handicapped in the development of formulas for the calculation of transient reactances by the lack of short-circuit test data on large machines. Furthermore, the transient reactance is subject to wide variation in any one machine. Due to magnetic saturation of the reactance flux paths, which is especially prominent in large solid rotor alternators, any increase in the amount of external reactance or decrease in the operating voltage makes a considerably greater percentage reduction in the initial short-circuit current. In this situation it has been the practice of designers to give reactance values that are conservatively low for short-circuit calculation, thus ensuring a reasonable margin of safety in the protection of these large machines.

Table IV—Timing of Cathode Ray Oscillograph

	CO Test	OCO Tests	Total
Number of tests	9	8	17
Number of correct current zeros	8	2	10
Per cent of selections of correct current zeros	89	25	59
Number of successful records	7	1	8
Per cent successful timing by current transformer	87	50	80
Successful records, per cent of total	78	12	47

On account of this reduction in short-circuit current, the tests failed in one respect; that of determining the performance of the circuit breaker when operating near its rated interrupting capacity.

With respect to recovery rate, however, it is felt that the test connections closely parallel the conditions of the final installation, and that in this respect the circuit breaker has been thoroughly tested and proved capable of performing its duty.

It should not be assumed from these tests that the performance of the circuit breaker would continue to be unaffected by the recovery rate if this rate were increased indefinitely. The performance of the breaker may be well described by the statement that, almost without exception, interruption was obtained on the first current zero after a gap of $^3/_4$ inch had been established between the contact tip and the gates. High as the recovery rates were carried, therefore, they remained in the range where the breaker was interrupting the circuit at the earliest point at which interruption could be expected with any circuit of appreciable power. But how far this range extends beyond the point to which tests were carried no one can say.

As is often the case with oscillograms, the pecu-

liarities of the records are of interest. In the films of the first and second series a beat is apparent in the highest frequency component; this is due to a slight difference in oscillating frequency between the first phase to clear and the last 2 phases to clear, which oscillate together when the first phase clears. Additional circuit-breaker bushings cause the last phases to have higher capacitance to ground, while the reactances remain the same.

In the records from group 2, the behavior of the cables is manifested in discontinuities appearing at about 70 microseconds and again at about 140 microseconds. These discontinuities are caused by waves reflected back from the Delaware end of the cables.

The effect of arc voltage in reducing the recovery rate has already been discussed.

The authors wish to acknowledge the suggestions made by E. B. Shew and others of the Philadelphia Electric Company and by J. K. Ostrander of the United Engineers and Constructors, Inc., toward the preparation of the paper and the courtesy of the Philadelphia Electric Company in making available the magnetic oscillograph records.

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Breaker Performance Studied by Cathode Ray Oscillograms

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Analyses of cathode ray oscillograms of circuit interruptions reveal characteristics of the circuits that are significant in the study of circuit breaker performance. While a complete analysis of such an oscillogram involves much detailed work, the study of several typical oscillograms reveals the significance of certain types of voltage variations and thus makes possible the analysis of similar oscillograms without detailed measurements. Several oscillograms made on typical laboratory circuits are presented and analyzed in this paper.

EXTENSIVE studies of circuit breaker performance by means of cathode ray oscillograms have disclosed significant phenomena of arc interruption. The studies have been facilitated by the great range of frequency response and the large time scale of these oscillograms, which permit accurate studies to be made based upon the voltage across the breaker terminals during the arcing period and during the recovery transient. A complete analysis of such an oscillogram involves a large amount of detailed work, but a study of several typical oscillograms reveals the significance of certain types of voltage variations and makes possible a quick and reasonably satisfactory analysis of other similar oscillograms without the necessity of making detailed measurements. Some typical oscillograms already have been discussed before the A.I.E.E.[1]; additional ones showing other types of phenomena are included in this paper.

The oscillograms selected were made on laboratory circuits, but apply also to field circuits having similar characteristics. Such circuits consist of 1 or 2 generators supplying power through reactors either directly or through transformers to a circuit breaker. The oscillograms chosen cover low currents, interrupted by normal and high speed breakers, high currents, and moderate currents on circuits having different natural frequencies.

Since the criterion of circuit severity is the rate of rise of recovery voltage, and since the time interval and voltage range used in the calculation of this rate are not specified by the term itself, a discussion of the method of measuring cathode ray oscillograms and determining circuit characteristics is included. Typical circuit characteristic curves of a high power laboratory also are given.

Briefly summarized, the principal points brought out in this paper and the conclusions reached are as follows:

1. The method of calculating the rate of rise of recovery voltage from cathode ray oscillograms of circuit interruptions should eliminate the effect of the breaker; a method accomplishing this is described here.

2. Circuit characteristics can be determined from cathode ray oscillograms of interruptions, supplemented by frequency measurements with oscillators and possibly by calculations. Calculations

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1. For all numbered references see list at end of paper.

of a simple circuit show that the published formulas do not give curves fitting those determined experimentally.

3. A circuit breaker opening a small current may have an unstable arc which causes the current to pass in a series of rapid impulses.

4. Breakers having arc extinguishing devices that make low current arcs unstable and build up the dielectric strength between contacts too rapidly during a half cycle produce high overvoltages.

5. The capacitance associated with circuits having a low natural frequency assists arc extinction not only by reducing the rate of rise of recovery voltage, but also by diverting current from the arc when the arc voltage rises at the end of the half cycle of arcing. This diversion of current tends to make the arc unstable and to cause the extinction of the arc to take place before the negative peak of voltage is reached at the beginning of the recovery voltage transient.

Methods of Measuring Cathode Ray Oscillograms of Circuit Breaker Performance

Circuit breaker performance is a function not only of voltage and current, but also of the circuit characteristics. Consequently, for any discussion of breaker performance it is desirable to have some simple measure of these characteristics. The criterions that have been proposed are based upon either the natural frequencies of the circuits or the rate of rise of recovery voltage. Those based upon frequency are not adequate, but are the easier to determine, the most common of these being simply a statement of the natural frequency of the circuit. This method of expressing the characteristics is satisfactory only if the circuit has but 1 natural frequency or if 1 predominates. Circuits that have 2 or more natural frequencies and circuits that are aperiodic, are not easily assigned an equivalent frequency; hence, such circuits are not readily compared on this basis. Moreover, a 132 kv circuit having a natural frequency of 10,000 cycles per second represents a relatively "difficult" circuit, but a 13.2 kv circuit having the same natural frequency represents a relatively "easy" circuit; hence, the significance of the natural frequency varies with voltage. For these reasons, criterions based upon natural frequency are being used less and less.

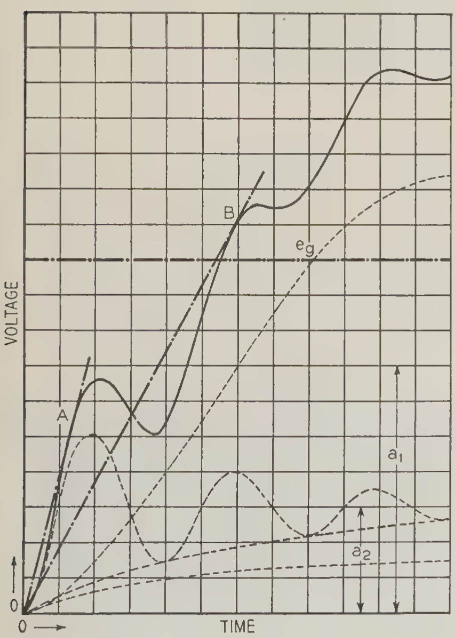


Fig. 1. Typical reconstructed recovery voltage transient

a_1—Amplitude of lower frequency component
a_2—Amplitude of higher frequency component
e_g—Normal frequency voltage

The other criterion, expressed as the rate of rise of recovery voltage, is not determined as easily as the natural frequency, but is applicable to all types of circuits and, when applied to individual tests, takes into account the magnitude of the restored voltage and the asymmetry of the current. In this method the rate at which voltage appears across the contacts of a circuit breaker is stated. Since this rate is not constant, but varies almost continuously during a transient, the value given is an average value derived by arbitrary assumptions.

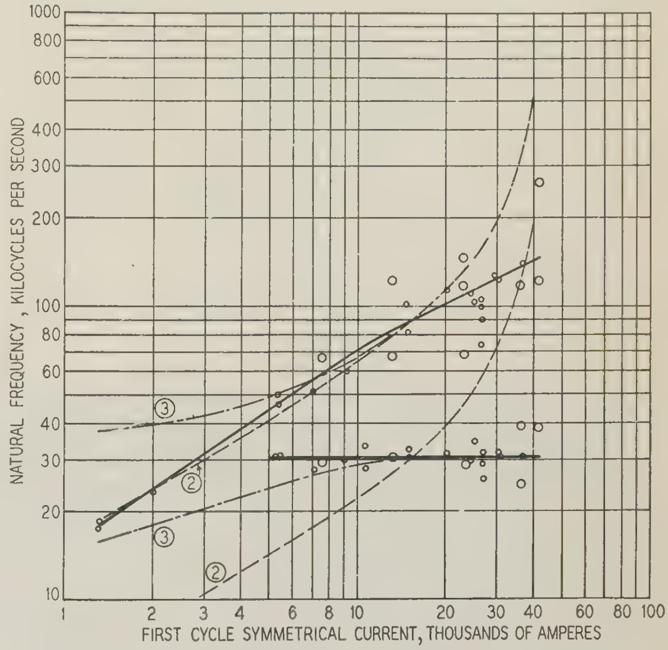


Fig. 2. Determination of the natural frequencies of a high power laboratory circuit

13.2-kv single-phase ungrounded circuit
o—From cathode ray oscillograms
O—From oscillator measurements
2—From Park and Skeats formulas (see reference 2)
3—From Juillard formulas (see reference 3)

Measurements of the average rate of rise of recovery voltage on a given test directly on the oscillogram are not satisfactory because of the effect of the breaker on the recovery transient as has been shown in a previous A.I.E.E. paper.[1] Sometimes the breaker causes only a slight increase in the amplitude due to the arc voltage, but at other times it causes an increased amplitude of the voltage wave produced either by a high arc voltage or by a sudden extinction of the arc, a shifting of the current zero due to high arc voltage, and/or a change in the whole nature of the transient due to the passage of a small current through the space between contacts after the arc is extinguished.

These effects of the breaker should be eliminated in determining the rate of rise of recovery voltage. The result should be the rate of rise in the circuit after a current interruption by an ideal breaker having zero arc voltage and passing no current after

the arc is extinguished. This should be done so that the breaker will receive credit for opening a difficult circuit even though its action reduces the rate of rise of recovery voltage, and so that it will not be given undue credit if it increases the rate of rise.

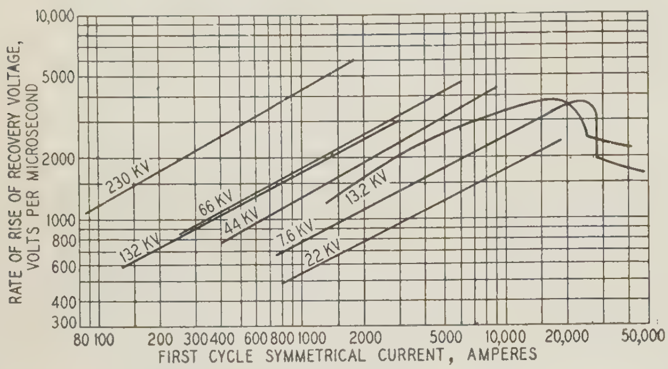


Fig. 3. Circuit characteristics of a high power laboratory

and the amplitude of the lower frequency (a_1) the remaining 70 per cent.

After the transient voltage has been plotted, the rate of rise can be determined. This is done by taking the slope of a line from the origin to a point on the transient. If the transient has a single frequency the line chosen will be a tangent that gives the maximum slope. However, when a high frequency component of relatively small amplitude is present, the maximum rate is associated with a tangent to the curve at less than a half cycle of this frequency (see *A* in figure 1). The actual voltage impressed on the breaker at this time, however, is small in comparison with the peak of the restored voltage (e_o), so this rate probably has little or no significance and should be neglected. How high this voltage should be in order to be significant is probably a function of the voltage of the circuit and the circuit breaker. On test circuits, voltages less than 80 per cent of the peak value of the normal frequency voltage (e_o) are neglected, but additional

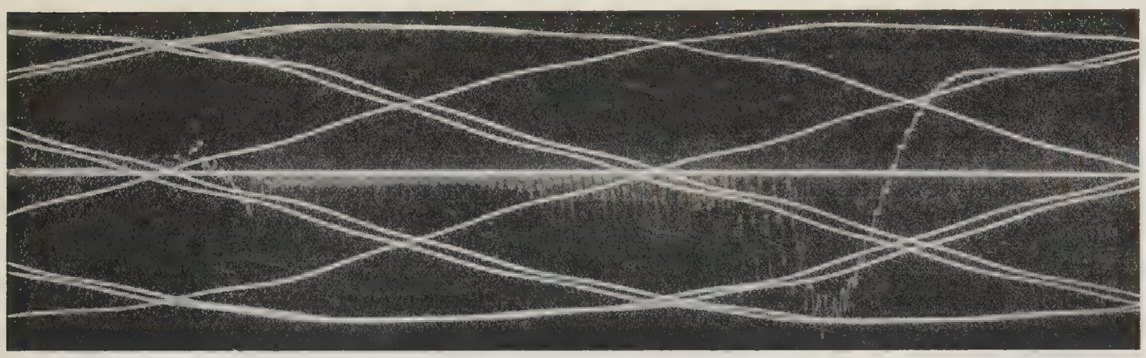


Fig. 4. Cathode ray oscillogram of the interruption of a single-phase 20-kv 6-ampere circuit

To eliminate the effects of the breaker, it is necessary to reconstruct the transient with data on the frequencies f_n, amplitudes a_n, and decrements x_n of the n components taken from the oscillogram. For oscillatory circuits the following formula is used, which gives the instantaneous voltage of the recovery transient, v, as a function of time t:

$$v = \Sigma a_n(1 - \epsilon^{-\alpha_n t} \cos 2\pi f_n t)$$

As given by this equation, the initial voltage at the beginning of the transient is zero, corresponding to the assumed arc voltage. The amplitudes of the component frequencies have the same relative magnitudes as in the oscillogram and their sum equals the restored voltage. The restored voltage is taken as the instantaneous value of the normal frequency voltage at the time the current normally would have reached zero at the end of its last half cycle if the voltage across the breaker had been zero. This definition is worded so that a breaker is given full credit for opening a circuit even though it brings about the interruption by first changing the phase angle of the current by the introduction of a resistance or high arc voltage, thereby reducing the actual rate of rise of recovery voltage. An example of a reconstructed transient is shown in figure 1. The amplitude of the higher frequency component (a_2) is assumed to be 30 per cent of the restored voltage

experience may justify the modification of this arbitrary limit. The rate of rise of recovery voltage for oscillatory circuits is the slope of a line drawn on the reconstructed transient from the origin, zero voltage, to a point representing a voltage at least 80 per cent of the normal frequency restored voltage and giving a maximum value to the rate of rise of recovery voltage; for example, see *B* in figure 1.

Some circuits are not oscillatory and the voltage rises on an approximately exponential curve to the restored voltage. For such a curve it is probable that the corresponding arbitrary minimum voltage limit used should be less than 80 per cent, but more data are required before it can be chosen so it will give measured rates of rise that will indicate the same severity of service as the same values obtained on oscillatory circuits.

Determination of Circuit Characteristics

The method used in determining the rate of rise of recovery voltage from cathode ray oscillograms of circuit interrupting tests has been described. The results obtained are a function of the circuit and of the particular test. The test determines the magnitude of the restored voltage and the asymmetry of the current. The circuit determines the frequencies, relative magnitudes, and damping of the components

of the transient. If the characteristics of the circuit alone are to be determined, the voltage can be assumed to be the value obtained with nominal system voltage and a symmetrical current.

On circuits where considerable testing is to be done, for example, those of high power laboratories, it is desirable to know the circuit characteristics so that by applying corrections for restored voltage and asymmetry the rate of rise can be determined for individual tests without cathode ray oscillograms being taken and analyzed. The characteristic curves can be obtained by measuring cathode ray oscillograms, but, unless tests are made particularly for this purpose, considerable time is required before the entire range of current is covered at each voltage. Consequently, it is desirable to have another method for calculating supplementary data. In laboratory circuits consisting of a generator and reactors there are usually 2 principal frequencies the amplitudes of which are approximately proportional to the inductances of the generator and the reactors, the higher frequency being associated with the inductance of the reactors. The frequencies can be determined by

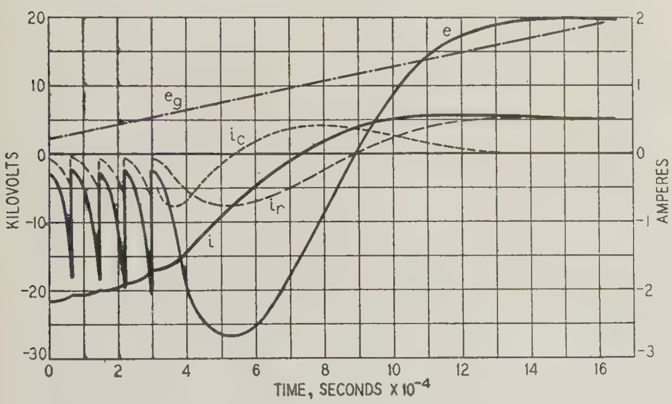


Fig. 5. Analysis of the oscillogram in figure 4

i —Total current
i_c—Current taken by capacitance
i_r—Current taken by cathode ray oscillograph
e—Recovery voltage transient
e_g—Normal frequency voltage

the use of an oscillator which impresses a voltage between the breaker terminals. This method has been used and has given results that have been in agreement with cathode ray measurements.

Curves of natural frequency as a function of the first cycle symmetrical current in a laboratory circuit are shown in figure 2. Data from cathode ray oscillograms are plotted as small circles, data from oscillator measurements as large circles, and 2 full-line curves are drawn to fit these points. Neither the cathode ray oscillograms nor the frequency measurements gave data that fit the curves exactly. In drawing a curve to fit such experimental data there is a big advantage in knowing the probable or theoretical shape of the curve. In some types of work if the shape of the curve is known and a few points are located the curve can be drawn. To try this method on the determination of the natural frequencies of laboratory circuits, curves derived from formulas were compared with the experimental data. The curves were calculated from published formulas.[2,3] These formulas give the natural frequencies as functions of the inductances and capacitances of the circuit. The inductances of the generator and reactors had been measured at 60 cycles by means of oscillograms which were taken to determine the reactance-current-time calibration. These values were used although they may not be correct for frequencies from 20,000 to 200,000 cycles per second. The capacitances had been measured by a portable bridge. As the accuracy of the capacitance measurements was subject to some doubt, and as only the shapes of the curves were desired, the values of capacitance used were calculated for each set of formulas from the frequencies found at 15,000 amperes. Therefore, all 3 sets of curves give the same values of frequency at this current. The earlier formulas[2] give a fixed ratio between the higher and lower frequencies, and curves derived from them do not fit the experimental data well except for the higher frequency at low currents. Curves derived from the other formulas[3] likewise do not fit the data, except for the lower frequency in the high current range. In calculating these curves

Fig. 6. Cathode ray oscillogram of the interruption of a single-phase 70-kv 20-ampere circuit

the assumption was made that the inductance of the reactors was the only variable. Probably the capacitances were not constant for the various reactor combinations, but only very large variations could change the shapes of the curves sufficiently to make them fit the experimental data. From the differences in the shapes of the curves, apparently there is considerable difficulty in making assumptions when deriving formulas for calculating the frequencies of circuits, and calculations should be used very cautiously even when only the shape of the curve is to be obtained. The natural frequencies can be obtained more accurately from cathode ray oscillograms and oscillator measurements.

After the natural frequencies of the circuits have been ascertained, the rate of rise of recovery voltage can be determined. For circuit characteristic curves, standard conditions are assumed to be a restored voltage equal to the nominal circuit voltage and an interruption at the time of peak voltage, corresponding to the zero of a symmetrical current in a reactive circuit. The voltage transients are plotted for several circuit conditions and the corresponding rates of rise determined by the method previously described. Some typical calibration curves of a high power laboratory with the work of which the author is associated are shown on figure 3. The curves for the circuits containing transformers are straight lines and a single frequency predominates at each current value. The curves for the 13.2 kv and 7.6 kv circuits are more complicated because of the presence of 2 frequencies. The effects of neglecting voltages below 80 per cent of the crest value of the normal restored voltage are discontinuities at 25,000 and 28,000 amperes and modifications of the curves at currents just below and above these values.

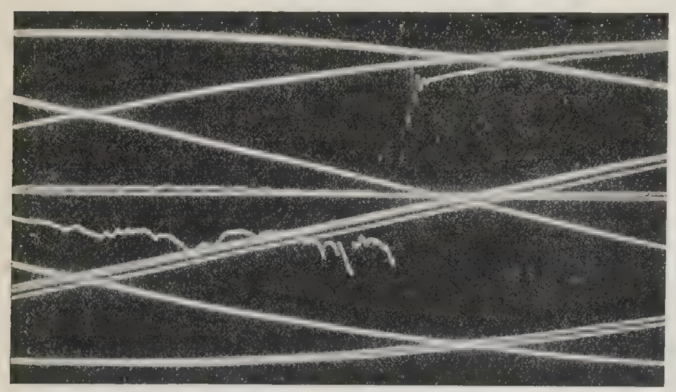


Fig. 7. Cathode ray oscillogram of the interruption of a single-phase 7.6-kv 75,000-ampere circuit

A smooth transition would be more desirable but an elaborate formula for the transition stage is not justified until the effect of high rates reaching only low values of voltage have been subjected to more study.

These circuit characteristic curves are used for determining the rate of rise on individual tests by reading the value corresponding to the laboratory setting and multiplying by a factor that corrects for the reduction in the actual normal frequency restored voltage. This factor is equal to the quotient of the instantaneous value of the normal frequency restored voltage at the time when the current would have reached zero if uninfluenced by the breaker, and the peak value of the nominal circuit voltage.

This factor may be split into 2 components: one is the ratio of the normal frequency restored voltage to the initial voltage; the other is a function of the asymmetry of the current. The following tabulation illustrates the effect of the asymmetry:

Ratio of Direct Component of Current to Peak Value of Alternating Component	Factor
0.00 (symmetrical current)	1.0
0.31	0.95
0.44	0.9
0.60	0.8
0.72	0.7
0.80	0.6
0.87	0.5
0.92	0.4
0.96	0.3

Only the very large degrees of asymmetry produce significant reductions in the rate of rise of recovery voltage. When the asymmetry is large and the natural period slow another correction for the change in the normal frequency voltage during the transient is necessary. Such a case is shown in figure 4.

Interpretation of Oscillograms

In a paper[1] presented before the A.I.E.E. during 1933, typical oscillograms were shown to illustrate the difference between good and poor circuit interruptions. Most of the tests had been made at 7,600 volts and about 10,000 amperes, but the points they illustrated are true for other currents and voltages. The oscillograms presented in the present paper illustrate additional phenomena occurring at low currents, an interruption by a breaker having a very high rate of deionization, the interruption of very large currents, and the effect of circuits of different natural frequencies.

The oscillograms presented here were made on a rotating-drum cathode-ray oscillograph which was described previously.[1] The oscillograph is connected to record the voltage across the terminals of a single pole of a circuit breaker interrupting single phase short circuits. The film which is 5 inches wide and 18 inches long is fastened to a rotating drum revolving at high speed and is exposed for a few cycles which include the time of interruption. As the drum has made several revolutions during this time, the beam has made several traces on the film. Since the phenomena at the time of arc extinction is the item of principal interest here, the oscillograms have been trimmed and only parts used in the illustrations. In both figures 4 and 6 the part is sufficiently large to show the entire period of interruption. Time varies linearly from left to right. The straight line through the middle of each oscillogram was traced while the contacts were still closed so that there was no voltage across the ter-

minals of the pole unit of the breaker. In both tests, the contacts separated at a time corresponding approximately with the left hand edges of the illustrations. The current wave went through zero in the first quarter, the circuit finally was opened at a point in the third quarter, and the recovery transient is shown at the right hand side. In figures 7 and 9 only the periods including the final current zero and the recovery transients are shown.

Interruption of a small current in a reactive high voltage circuit is shown in figure 4. The effective value of the symmetrical component at the time of interruption was 5.8 amperes and the normal frequency voltage 20 kv. However, the current was asymmetrical and was interrupted during the small half cycle which had a maximum of about 3 amperes. At this low current the arc in oil was unstable and, although the magnetic oscillogram did not indicate it, the current through the breaker after the contacts parted was intermittent, the time between impulses being less than 0.0001 second. This resulted in a succession of voltage peaks which took the place of the usual arc voltage as can be seen on the cathode ray oscillogram, figure 4.

For a better study of the conditions existing during this circuit interruption, 4 periods during which the current through the breaker was interrupted momentarily are shown in figure 5 with the low-amplitude high-frequency component of the recovery transient omitted. During these periods, the current flowing through the inductive part of the circuit caused the small capacitance across the breaker (the capacitance of the leads, bushings, etc., amounting to about 4.05×10^{-9} farad) to be charged to a voltage of 18 to 21 kv at which time the gaps between contacts broke down and again passed current. Final extinction occurred when the current no longer was large enough to charge the capacitance to a voltage higher than the dielectric strength of the gaps. The current i_r taken by the resistance-coupled cathode-ray oscillograph was of importance in the low current interruption as it caused the rapid damping of the oscillation. The equation for the recovery transient between $t = 3.2 \times 10^{-4}$ and $t = 16 \times 10^{-4}$ second is

$$e = \epsilon^{-\frac{1}{2RC}t} \times A \sin \sqrt{\frac{1}{CL} - \frac{1}{(2RC)^2}}\,(t - 3.2 \times 10^{-4})$$

where

e = voltage of transient
R = 36,000 ohms
C = 4.05×10^{-9} farad
L = 9.1 henries
A = 97 kv
t = time in seconds

The resistance, 36,000 ohms, corresponds to the resistance of the potential dividers for the oscillograph. It reduces the frequency from 828 cycles to 627 cycles per second in addition to causing the rapid damping.

This typical oscillogram shows that the interruption of a low current is accomplished easily because the arcs are unstable in oil. After the contacts part a series of short discharges occur between contacts, until the voltages impressed across the gaps no longer rise above their dielectric strengths. The voltages across the gaps are a function of the current flowing in the circuit at the instant of arc extinction, the inductance and capacitance of the circuit, and time.

When a breaker is equipped with very effective arc rupturing devices and designed for high speed operation, the deionization activity may be so great that if the breaker is used on voltages lower than its rating very high overvoltages are produced. Figure 6 shows a test on which an experimental 287 kv breaker designed for high speed operation interrupted a current of 20 amperes at 70 kv, single phase. During the half cycle of arcing the arc was unstable, the current intermittent, and voltages as high as 276 kv appeared 10 times. Higher voltages are not recorded on the film but a calculation of the peak value from the rate of rise and the time indicates that a voltage of 360 kv was reached. This is more than 3.5 times the peak of the normal frequency voltage. The test brings out an important point in circuit breaker design: It indicates that in striving for the rapid clearing of short circuits, care must be taken that excessive overvoltages are not produced. As has been pointed out by Slepian,[4] the formation of an arc in a circuit breaker prevents the current from being interrupted abruptly when the contacts part and permits the current to be reduced gradually to zero. However, if the interrupting means is so effective that the arc is not stable and the dielectric strength of the gap is increasing very rapidly, the arc cannot exist until the magnetic energy stored in the circuit is low and high overvoltages must be expected.

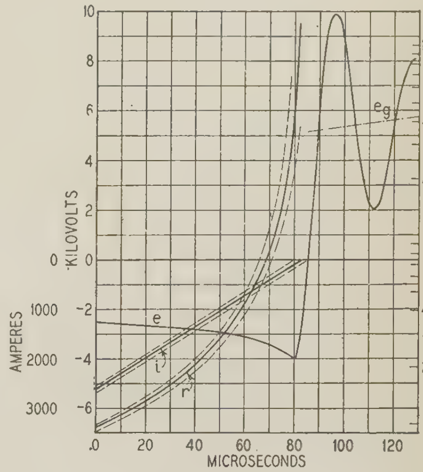


Fig. 8. Analysis of the oscillogram in figure 7

i—Current through circuit breaker
e—Recovery voltage transient
e_g—Normal frequency voltage
r—Effective resistance of arc space

The interruption of a very heavy current is shown in figures 7 and 8. The first cycle symmetrical current was about 75,000 amperes at 7,600 volts. The current, i, approached zero at a rate of 31 amperes per microsecond. The magnitude of the current was so great that the current charging the capacitance and the current taken by the oscillograph were negligible. The rate at which the effective resistance (e/i) of the arc space increased is shown by the curve r. The exact instant at which the current reached zero is not determined easily, but fortunately the effect of an error in locating it makes no great differ-

ence in the results obtained. On either side of the current curve are dashed curves that correspond to current zeros occurring before and after the instant chosen, and the corresponding resistance curves are on either side of curve *r*. These curves demonstrate that a small error in locating the current zero does not change the general character of the calculated resistance curve. Because of the greater rapidity with which the current approaches zero at these high currents, the deionizing activity must be much greater than is necessary for good operation at lower currents. The rapid rise of the resistance curve shows the effectiveness of the deionizing grids used on this test.

The performances of a plain-break oil circuit breaker interrupting 2,400 amperes at 6,850 volts on 2 different circuits are shown on figures 9 and 10. The first test was made with a circuit having a natural frequency of 13,500 cycles per second. The arc voltage at the end of the half cycle was about 1,800 to 2,000 volts and decreased gradually as the current approached zero. Since the effective resistance of the arc space was only about 240 ohms at the time the voltage passed through zero, the current reversed and flowed in the opposite direction. This current increased to about 22 amperes before the gap broke down. The rate of dionization was not high enough to bring about the interruption of the arc at this contact separation on a circuit having a natural frequency of 13,500 cycles per second.

In contrast to this is the interruption during the second test of the same current and voltage at approximately the same contact separation on a circuit having a natural frequency of 5,250 cycles per second. In this test, as the current approached zero the arc voltage, which was lower than on the first test, increased causing the current through the breaker to be reduced by the amount of the charging current of the capacitance across the breaker terminals. This current was about 5 amperes and caused the arc current to reach zero earlier than it would have otherwise, and then caused the voltage across the breaker to increase for about 5 microseconds before the negative peak of the 5,250-cycle sine-wave recovery transient was reached. This relatively slow transient then permitted the dielectric strength of the gap to increase for about 100 microseconds before the maximum voltage was applied across it. From these tests it can be concluded that the lower frequency circuit aids the extinction in 2 ways: the larger capacitance diverts more current from the arc if the voltage starts to rise at the end of the half cycle, thereby making possible the interruption of the arc before the current normally would have reached zero; and the lower frequency causes the voltage to be applied less rapidly to the arc space. In these 2 tests, the difference was sufficient to make the arcs restrike on the 13,500 cycle circuit and extinguish on the 5,250 cycle circuit.

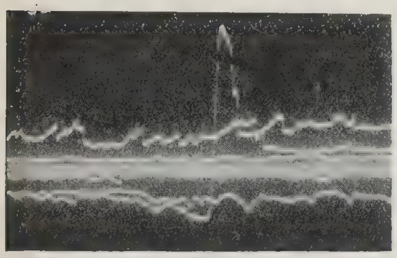
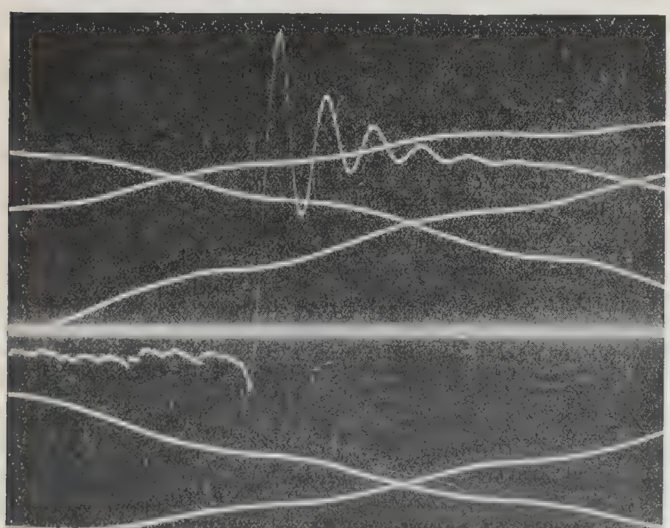


Fig. 9. Oscillograms of interruptions of single-phase 6,850-volt 2,400-ampere circuits having natural frequencies of (left) 13,500 and (below) 5,250 cycles per sec



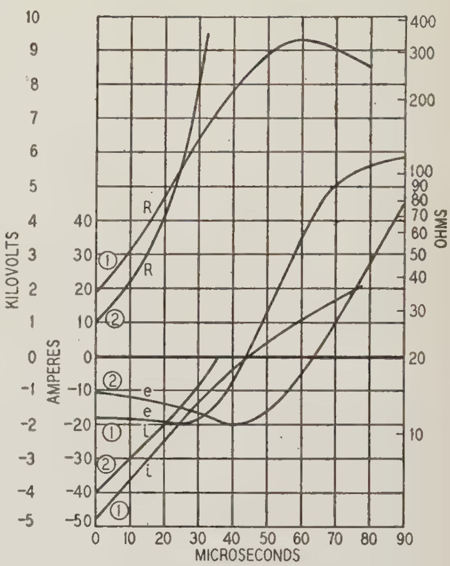


Fig. 10. Analysis of the oscillograms in figure 9

1—Natural frequency of circuit 13,500 cycles per second
2—Natural frequency of circuit 5,250 cycles per second
i—Current through circuit breaker
e—Recovery voltage transient
R—Effective resistance of arc space

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$$\frac{1}{2\pi}\sqrt{\frac{(3C_1 + C_2) + \sqrt{9C_1^2 - 2C_1C_2 + C_2^2}}{2L_1C_1C_2}}$$

$$\frac{1}{2\pi}\sqrt{\frac{(3C_1 + C_2 - \sqrt{9C_1^2 - 2C_1C_2 + C_2^2}}{2L_1C_1C_2}}$$

3. Conference Internationale des Grands Reseaux Electriques A Haute Tension June 1933, Report 31—Report of the committee on high voltage breakers, E. Juillard.

$$fo_1 = \frac{1}{2\pi\sqrt{(L_1 + L_2)\,C_2 + L_1\,C_1}}$$

$$fo_2 = \frac{1}{2\pi}\sqrt{\frac{(L_1 + L_2)\,C_2 + L_1\,C_1}{L_1\,C_1\,L_2\,C_2}}$$

4. Discussion by J. Slepian. A.I.E.E. Trans., v. 49, 1930, p. 445.

Stability of the General 2-Machine System

The transient tability of the general 2-machine system is considered in this paper. Introduction of an equivalent system with concentrated inertia at one end is shown to facilitate the direct application of the equal area method of analysis to the general 2-machine system. Heretofore the equal area method has been confined to certain special 2-machine systems.

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CONCLUSIONS regarding transient stability of 2-machine systems are frequently based upon the first swing-apart of the machines. This involves the assumption that if the machines once come to rest with respect to each other the system will survive the shock caused by the disturbance in question, and gives rise to the "equal area" criterion of stability. (See, for instance, references 1 to 4, and other papers.) Although the general mathematical formulation of the latter has been established (see reference 2, eq 5, followed by a formula involving its application to a general 2-machine system when the clearing of the fault is either instantaneous or long-delayed), its practical application as a simple and actually visualizable criterion has so far been confined to such 2-machine systems as those where:

(1) One end of the system definitely is an infinite bus; or,

(2) With retention of the actual machine inputs and the actual circuit, the inertia can be concentrated at one end so that an infinite bus is obtained at the other.

Concentration of the inertia at one end of the system under the conditions imposed in point 2 above requires that (*a*) the network connecting (and including) the machines contains reactance only; and (*b*) one machine operates as a generator and the other as a motor. [Evidently (*b*) is a consequence of (*a*).]

It is the purpose of this paper to call attention to the fact that also the general 2-machine system may be represented by an equivalent system with the inertia concentrated in an equivalent machine at one end of an equivalent circuit, and with an infinite bus at the other. The input to the equivalent machine will differ from that of either machine and is a function of the actual inputs and the inertia constants. Similarly, the equivalent circuit (including the equivalent machine) and the corresponding equivalent power-angle curve depend upon the actual circuit and the inertia constants of the machines.

The equivalent system may be used for complete point-by-point analyses of relative motion equally as well as the actual general 2-machine system which it represents. Moreover it lends itself to solutions by the equal area method and hence makes the direct application of this stability criterion practical also to problems involving general 2-machine systems. The equivalent system, on the other hand, is not applicable to the determination of the absolute accelerations and speeds of the machines.

The General 2-Machine System

The general 2-machine system involves 2 synchronous machines connected by a dissipative network which may or may not contain static loads (or their equivalent). It represents an important case and, quite frequently, practical transient-stability analyses are based upon this layout. It may be identical to the system actually at hand but is more often the result of a simplification of the actual system.

The stability of such a system (for instance, the one in Fig. 1), when its equilibrium is upset by a disturbance, may in general be examined by inspecting the swing curves of the machines. Such swing curves are obtained by solving the differential equation (see Appendix for the meaning of symbols)

$$M \frac{d^2\delta}{dt^2} = P_i - P = \Delta P \tag{1}$$

for each machine by means of a point-by-point process. Either the angle of each machine with respect to some standard reference line or else the angle between the machines (the difference between the separate angles) may be plotted versus time. The former indicate the actual movement of each machine, the latter their relative movement, which of course is of principal interest from the standpoint of stability. Swing curves for a general 2-machine system are illustrated in Fig. 3.

The primary thing during a point-by-point analysis is the determination of the output at each point as the calculations progress. Neglecting damping and assuming that the entire circuit, including the machines, is linear, i. e., the saturation in the machines is neglected, the output may be determined

(1) by direct calculation; or

(2) from power-angle curves; or

(3) from circle diagrams.

The outputs of the machines are given by

$$P_1 = \frac{E^2_1}{Z_{11}} \cos \theta_{11} - \frac{E_1E_2}{Z_{12}} \cos (\delta + \theta_{12}) \tag{2}$$

and

$$P_2 = \frac{E^2_2}{Z_{22}} \cos \theta_{22} - \frac{E_1E_2}{Z_{12}} \cos (\delta - \theta_{12}) \tag{3}$$

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1. For all numbered references see list at end of paper.

(The 2 equations just given apply to non-salient-pole machines, and may be found in several places in the literature, for instance, see reference 2.)

Three sets of these equations must in general be available: (*a*) for operation with the system intact; (*b*) for operation with the system faulted; and (*c*) for operation with the faulty section cleared. (If the faulty section is cleared by sequential switching part (*c*) may require 2 sets of equations. In systems with reactance compensation by series capacitors additional sets may also be necessary.) Discontinuities in the outputs occur when the fault comes on and when it is cleared. The initial operating angle is obtained from the first set. Using this angle in the second set gives the outputs immediately after the occurrence of the fault. These outputs in connection with the inputs to the machines fix the initial power differentials, assumed constant during the first interval. (Modification in regard to this assumption is evidently possible and depends, in general, on the accuracy desired.) The outputs for successive intervals are obtained from the same set of equations by substituting the proper system angles. When the time elapsed equals the clearing time, the third set of equations supersedes the second. The outputs immediately following the clearing of the fault are determined by using the "clearing angle," i. e., the system angle at the instant of clearing, in these equations.

Fig. 1. General 2-machine system

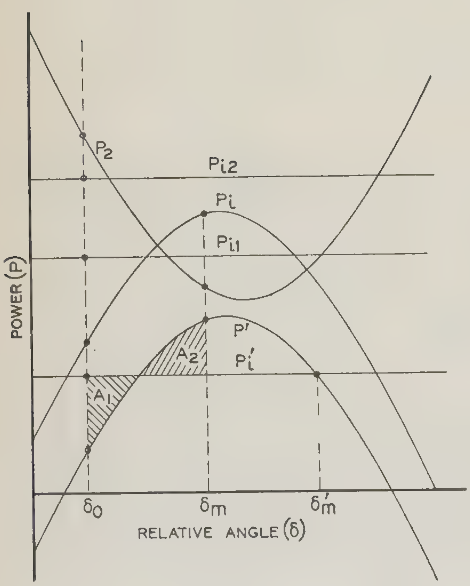

Fig. 2. Actual and equivalent power - angle curves and input lines for a general 2-machine system

The maximum angle δ_m is reached when the areas A_1 and A_2 are equal

Representation of Performance of the General 2-Machine System by a Single Equivalent Power-Angle Curve

As previously stated, it has been shown that in the special case of 2-machine systems where one machine operates as a generator and the other as a motor and the circuit contains reactance only, it was permissible to concentrate an equivalent mass at one end of the system and consider the other as an infinite bus. (See references 1 and 2, and other papers.) The circuit itself was to be retained as in the actual layout and the input to the equivalent machine was to be the same as the input to the actual machine.

A somewhat similar procedure is possible also with the general 2-machine system. It is possible also here to locate a machine with an equivalent mass at one end, and to consider the other end as an infinite bus and hence enable the solution to be based upon a single power-angle curve. In the general case, however—and this distinction should be carefully noted—it is necessary (1) to modify the circuit so as to obtain an equivalent power-angle curve, and (2) to use an equivalent input to the machine.

The relative acceleration of the 2 machines is given by

$$\frac{d^2\delta}{dt^2} = \frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2} = \frac{P_{i1} - P_1}{M_1} - \frac{P_{i2} - P_2}{M_2} \qquad (4)$$

which for the purpose of getting an equation of standard form (corresponding to eq 1) may be written

$$\frac{M_1M_2}{M_1 + M_2}\frac{d^2\delta}{dt^2} = \frac{M_2\Delta P_1 - M_1\Delta P_2}{M_1 + M_2} = \frac{M_2P_{i1} - M_1P_{i2}}{M_1 + M_2} - \frac{M_2P_1 - M_1P_2}{M_1 + M_2} = P'_i - P' \qquad (5)$$

or, more simply, as

$$M_0\frac{d^2\delta}{dt^2} = P'_i - P' = \Delta P' \qquad (6)$$

Here the equivalent input P'_i is given by

$$P'_i = \frac{M_2P_{i1} - M_1P_{i2}}{M_1 + M_2} \qquad (7)$$

and the equivalent output P' by

$$P' = \frac{M_2P_1 - M_1P_2}{M_1 + M_2} \qquad (8)$$

while the equivalent inertia constant M_0, as in the simpler case, is obtained by "paralleling" the actual inertia constants of the 2 machines, and is hence given by

$$M_0 = \frac{M_1M_2}{M_1 + M_2} \qquad (9)$$

Equation 6 is, as seen, of exactly the same form as that for a machine connected to an infinite bus through a circuit of arbitrary constants. The stability of the general 2-machine system may be correctly examined by the solution of this equation by point-by-point or other methods. Hence the general 2-machine case at hand has been reduced to that of an equivalent generator supplying power over an equivalent circuit to an infinite bus. The input to the equivalent machine is a function of the inputs to the actual machines and the inertia constants, while the output of the equivalent machine similarly depends upon the outputs of the actual machines and the inertia constants.

From the standpoint of relative motion, this representation, as well as eq 6 based upon it, is exact in every respect (subject, of course, to the usual limitation resulting from the assumption of constant actual speed of rotation, i. e., constant relationship between torque and power). The inputs may be constant or variable, and the outputs may or may not include the effect of damping. Its use in stability solutions based upon simplified criteria, however, is practical only when the inputs are constant and the damping neglected. Under these conditions the equivalent input is fixed and the output is a function of the internal voltages of the machines and the displacement angle between them (i. e., the displacement angle between the equivalent machine and the infinite bus).

Introducing the expressions for the outputs from eqs 2 and 3 and collecting constant and variable terms, eq 6 becomes

$$M_0 \frac{d^2\delta}{dt^2} = P'_i - \frac{M_2 \frac{E^2_1}{Z_{11}} \cos \theta_{11} - M \frac{E^2_2}{Z_{22}} \cos \theta_{22}}{M_1 + M_2} + \frac{E_1E_2}{(M_1 + M_2)Z_{12}} [M_2 \cos (\delta + \theta_{12}) - M_1 \cos (\delta - \theta_{12})] \quad (10)$$

By combining the trigonometric functions, this equation again reduces to

$$M_0 \frac{d^2\delta}{dt^2} = P'_i - P' = P'_i - [P'_c - P'_m \cos (\delta + \psi)] \quad (11)$$

Here the displacement term, the amplitude, and the phase angle of the equivalent sinusoidal power-angle curve are given by

$$P'_c = \frac{M_2 \frac{E^2_1}{Z_{11}} \cos \theta_{11} - M_1 \frac{E^2_2}{Z_{22}} \cos \theta_{22}}{M_1 + M_2} \quad (12)$$

$$P'_m = \frac{E_1E_2}{(M_1 + M_2)Z_{12}} \sqrt{M^2_1 + M^2_2 - 2M_1M_2 \cos 2\theta_{12}} \quad (13)$$

and

$$\psi = \tan^{-1}\left(\frac{M_1 + M_2}{M_2 - M_1} \tan \theta_{12}\right) \quad (14)$$

In Fig. 2 are shown actual and equivalent power-angle curves and input lines for a representative general 2-machine system.

Simplified Stability Criterion Applied to the General 2-Machine System

This criterion assumes that if the machines come to rest with respect to each other during their first swing apart, the system is stable. The mathematical formulation (see reference 2), of this criterion is

$$\int_{\delta_0}^{\delta_m} \left(\frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2}\right) d\delta = \int_{\delta_0}^{\delta_m} \frac{\Delta P'}{M_0} d\delta = 0 \quad (15)$$

In this equation the power differentials ΔP_1 and ΔP_2 may be represented by functions with any arbitrary number of discontinuities. Hence the criterion inherently provides for the inclusion of switching, fault clearing, etc. As a matter of fact, its validity definitely depends upon all operations causing discontinuities taking place before the maximum angle is reached. (If this is not the case, however, it is possible to extend the interpretation of the criterion. Not only must the machines come to rest with respect to each other during their first swing apart, but also during subsequent swings together or apart until all discontinuities are included. Not until then may actual conclusions be drawn in regard to the stability situation.) If stability is to be present it is evident that the acceleration (or retardation, as the case may be) of the machines with respect to each other must change sign during the first swing apart. In other words, the term $(\Delta P_1/M_1 - \Delta P_2/M_2) = \Delta P'/M_0$ must change sign. If it does not, it is evident that the integral in eq 15 can never be zero, the machines will continuously swing apart, and stability is definitely lost.

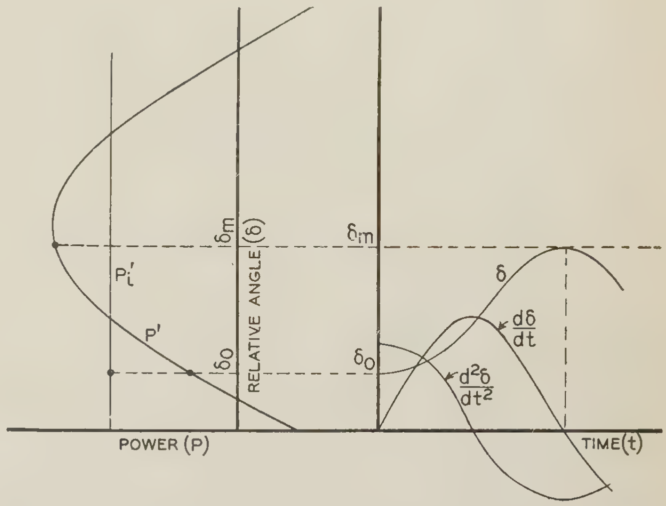

Fig. 3. Equivalent power-angle curve and time curves of relative angle, slip, and acceleration for a general 2-machine system with loading below the critical

Assuming that the acceleration changes sign, and also that the condition given by eq 15 is satisfied so that the system is stable, there are 2 possibilities in regard to the value of the acceleration $(\Delta P_1/M_1 - \Delta P_2/M_2)$ at maximum angle, namely:

(1) The acceleration may have a finite value.

(2) The acceleration may be zero, as indicated by

$$\left(\frac{\Delta P_1}{M_1} - \frac{\Delta P_2}{M_2}\right) = \frac{\Delta P'}{M_0} = 0 \quad (16)$$

or simply

$$\Delta P' = 0 \quad (17)$$

indicating that the equivalent power differential is zero.

In case 1, above, the system is stable with a margin, i. e., the loading is below the critical. Case 2 represents the limiting case. The loading is critical and equal to the transient power limit of the system for the disturbance in question.

Equivalent power-angle curves as well as time curves of angle, rate at which the machines swing apart (relative slip), and acceleration are plotted for the 2 cases in Figs. 3 and 4, respectively. Either

case indicates stability. In the former the machines come to rest with respect to each other while the acceleration still is negative. This would cause the machines to swing together again and oscillate with respect to each other before finally merging into new steady-state conditions. In the second case, where the load is critical, the machines come to rest with respect to each other and the acceleration becomes zero simultaneously. The system is aperiodic and the new steady-state conditions, reached at the end of the first swing, are represented by the maximum angle. (It is evidently necessary that some margin actually be present. If exactly the critical load were carried and, in accordance with the above, the system attempted to settle at the maximum angle, the operation here would be statically unstable and could not be sustained except under conditions of dynamic equilibrium.)

There are 2 methods of applying the stability criterion, namely:

(1) Use eq 15 and examine whether it yields a solution for the maximum angle δ_m. If it does, the system is stable; if no solution exists, the system is unstable.

(2) Find the critical angle δ'_m from eq 16 or 17. Evaluate and examine the sign of eq 15 for this maximum angle ($\delta_m = \delta'_m$). If negative, the system is stable; if zero, critical load conditions exist; and if positive, the system is unstable.

The simplified stability criterion for 2-machine systems expressed by eq 15 may be translated into an "equal area" conception. Evidently

$$\int_{\delta_0}^{\delta_m} \Delta P d\delta = \int_{\delta_0}^{\delta_m} (P_i - P) d\delta \tag{18}$$

represents an area, namely, the area between input and output curves, plotted versus angle, and bounded by the initial and maximum angle. Hence eq 15 may be modified to

$$\frac{1}{M_1}\left(\begin{array}{l}\text{net area (1)}\\ \text{between } \delta_0 \text{ and } \delta_m\end{array}\right) = \frac{1}{M_2}\left(\begin{array}{l}\text{net area (2)}\\ \text{between } \delta_0 \text{ and } \delta_m\end{array}\right) \tag{19}$$

The system is stable when the two areas thus defined and divided by their respective inertia constants are equal. Making use of it in this form represents the so-called equal-area method.

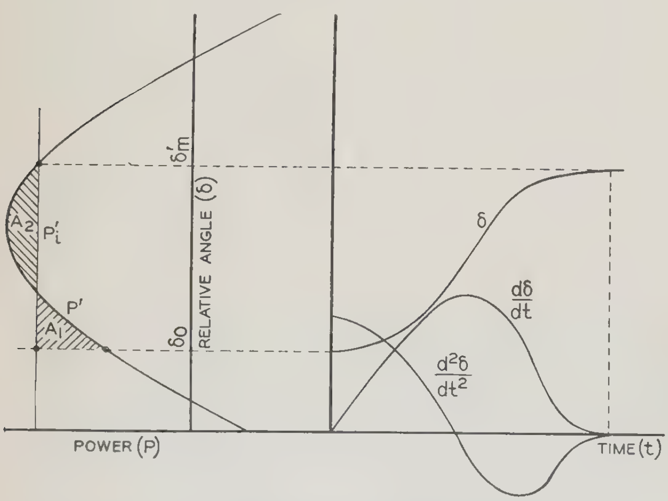

Fig. 4. Equivalent power-angle curve and time curves of relative angle, slip, and acceleration for a general 2-machine system for critical load conditions

Stability requires that the area A_1 be smaller than or—at the limit—equal to the area A_2

To apply this equal-area criterion of stability directly on the power-angle curves, however, is not practical when separate power-angle curves are used because the optimum angle to which the system may be permitted to swing is not inherently defined geometrically by the power-angle curves and the input lines (see Fig. 2). With separate power-angle curves the graphical determination of optimum angle requires an auxiliary plot of relative acceleration ($\Delta P_1/M_1 - \Delta P_2/M_2$) versus angle. Explicit use of the equal-area method, therefore, as a criterion of stability in the 2-machine system is especially convenient and practical when the inertia is concentrated at one end so that an infinite bus is obtained at the other, i. e., when the equivalent system previously described is utilized.

With respect to the equivalent power-angle curve, the equal-area method is directly applicable as such. The optimum angle is here fixed by the intersection of the equivalent power-angle curve and the equivalent input line. Referring to Fig. 4, stability requires that the area A_1 be smaller than or—at the limit—equal to the area A_2.

Appendix

List of Symbols

E_1 = internal voltage of machine 1 (voltage behind transient reactance)
E_2 = internal voltage of machine 2 (voltage behind transient reactance)
M_1 = inertia constant of machine 1
M_2 = inertia constant of machine 2
M_0 = inertia constant of equivalent machine
P_1 = output of machine 1
P_2 = output of machine 2
P_{i1} = shaft input to machine 1
P_{i2} = shaft input to machine 2
P' = output of equivalent machine
P'_i = shaft input to equivalent machine
P'_c = displacement of the equivalent sinusoidal power-angle curve
P'_M = amplitude of the equivalent sinusoidal power-angle curve
ΔP = power differential (difference between input and output)
$\Delta P'$ = power differential of equivalent machine
Z_{11} = driving-point impedance at machine 1
Z_{22} = driving-point impedance at machine 2
$Z_{12} = Z_{21}$ = transfer impedance between machines
t = time
θ_{11} = angle of driving-point impedance Z_{11}
θ_{22} = angle of driving-point impedance Z_{22}
$\theta_{12} = \theta_{21}$ = angle of transfer impedance Z_{12} or Z_{21}
δ = displacement angle between machines
δ_0 = initial displacement angle between machines
δ_m = maximum displacement angle between machines under stable conditions
ψ = phase angle of equivalent power-angle curve
K = (with appropriate subscripts) a constant
A = (with appropriate subscripts) an area

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Fault and Out-of-Step Protection of Lines

The stability characteristics of a typical high voltage transmission circuit have been considered together with the requirements for short-circuit protection, as a basis for the selection and application of relay protective devices. In this paper, the performance of the 132 kv New York Edison-Niagara Hudson interconnection under fault and swing conditions is analyzed, the characteristics of various protective devices are discussed, and the performance of the selected equipment under both calculated and actual operating conditions is given. A protective scheme involving carrier current control is shown to be highly satisfactory.

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THE rapid expansion during recent years of large capacity high voltage interconnections and the operating experience attendant thereto, have resulted in the promotion of intensive studies along many fronts to improve the operating efficiency and reliability of these interconnections, particularly those studies which have been concerned with the protective features. As a consequence, a tremendous impetus has been given to the development of circuit breakers and relays. In addition there is perhaps a more general appreciation that the power limits of important tie lines under transient and steady state conditions are factors which warrant careful consideration in advance of actual construction commitments.

It is well known, of course, that protective relay equipment was developed primarily and used almost exclusively for protection against faults. To be sure, qualifications have been added from time to time as the requirements became more fully evident and the means of their realization better understood, and these factors have led to the development of many important improvements in such devices both in regard to their reliability and capabilities. While fault clearing with all the modifying requirements now recognized as essential, such as selectivity, reliability, high operating speeds, etc., is highly effective, there is still another important factor which has been given but little publicity. This has to do with relay performance during system oscillations or power swings. This paper is intended to focus attention on this point.

When the 132 kv interconnection of the New York Edison-Niagara Hudson systems was projected it was realized that the exacting requirements which were established required careful consideration of all factors which concerned the service reliability of this important link between 2 large systems. In so far as the authors of this paper are aware it is believed that this is the first instance in which the stability characteristics have been coördinated with requirements for fault protection in designing the relay protective equipment. It is thought, therefore, that a discussion and exposition of the studies which were made in this instance may serve to establish a new approach for the protection of similar important lines and also encourage the development of further refinements and improvement in this branch of electrical engineering as a further step toward broadening the scope of its usefulness.

In presenting this paper it is the intent of the authors to outline the major requirements, to present the results of the short-circuit and stability studies and illustrate how both influenced the choice of the protective equipment selected, and finally to present a summary of actual operating experience. Following are the conclusions drawn as a result of the study presented in this paper:

Conclusions

The proper choice of protective equipment is primarily predicated on an accurate knowledge of the performance of the protected circuit during fault conditions and of the related behavior of the protective devices. For important tie lines, an analysis of line performance during power swings and out-of-step conditions is fully as important as the performance during faults, if the most successful application of protective devices is to be realized. It is, of course, equally important to have a knowledge of the performance of the protective devices under the same conditions for a proper choice of equipment.

With all facts available and by the use of suitable high speed protective equipment it should be possible not only to protect against all types of line faults but also to maintain the line in operation during power swings within its stable power limits and to separate 2 systems at a preferred and predetermined location when out-of-step conditions develop.

Under favorable conditions it may be possible to provide satisfactory protection against faults and also to secure suitable control of swing and out-of-

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step conditions by the same set of relays. Where this cannot be realized a separate relay should be provided expressly for out-of-step protection.

The carrier current system for control of protective relays has demonstrated its superiority to other schemes thus far developed for protection of high voltage, open wire tie lines, and represents the nearest practicable approach to pilot wire or current comparison methods. There is still room, however, for considerable improvement, notably in reduction of the operating time, more positive control of out-of-step protection, adaptation to cable circuits, reduction in first cost, and simplification of testing.

Major Connections

The principal circuits of the Eastern division of the Niagara Hudson system in the State of New York and the twin circuit tie line between the Pleasant Valley substation of this system and Hell Gate generating station of The New York Edison system are shown in figure 1. A major portion of the Niagara Hudson transmission system is operated at 110 kv but this voltage is stepped up to 132 kv at the

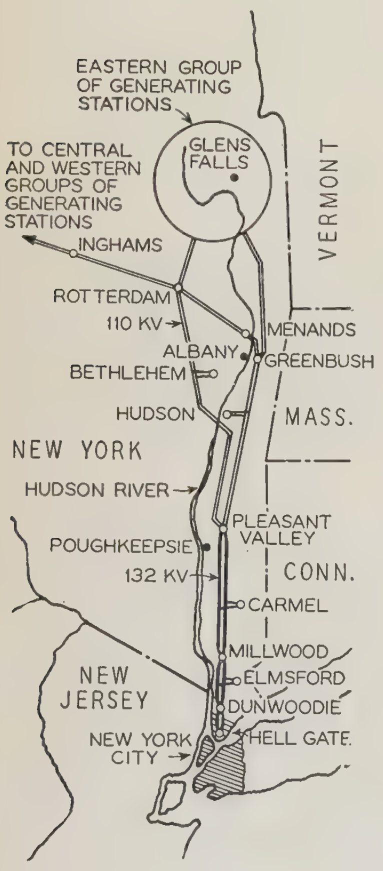


Fig. 1. Principal 110 kv and 132 kv circuits of the New York Edison-Niagara Hudson systems

The 132 kv interconnection is indicated by the heavy lines below Pleasant Valley substation

Pleasant Valley substation for the interconnection with The New York Edison system. This transformation is effected by means of 2 banks of autotransformers each rated at 100,000 kva, 110/132/13.2 kv, the 13.2 kv tertiary windings being used for the supply of 2 30,000 kva synchronous condensers.

The 2 132 kv overhead circuits pass through the territory of the Westchester County Lighting Company and the Yonkers Electric Light and Power Company, stepping down to 13.8 kv at Millwood, Elmsford, and Dunwoodie substations to serve local loads at these points. At Dunwoodie, connection is made to 2 132 kv underground cable circuits which complete the interconnection to the Hell Gate generating station of The New York Edison system, where each cable circuit is stepped down to the 13.8 kv generating bus potential through a 100,000 kva bank of transformers. The system neutral is solidly grounded at Pleasant Valley, Dunwoodie, and Hell Gate.

The interconnection between Pleasant Valley and Hell Gate and the connections to Westchester County substations are indicated in figure 2. The Carmel substation was added subsequent to the completion of the studies discussed in the paper and its effect in acting as a source of fault current is not included. The limited current available from this source may however, be neglected.

Major Requirements

As the 2 132 kv lines constitute the principal source of supply to Westchester County with a total peak load in the order of 75,000 kw served from 18 substations it was especially important that all reasonable steps be taken to insure the continuity of service to this area for all contingencies which could be anticipated as well as to preserve the reliability of the interconnection for power interchange purposes.

The following requirements therefore were established for the relay protective features to serve as a criterion of their effectiveness in maintaining the desired degree of service dependability.

1. All faults must be cleared in the minimum practicable time in order to maintain a high level of transient stability, and to minimize the probability of faults on one circuit communicating to the other.

2. The protective equipment must be adaptable to single circuit or parallel circuit operation as operating conditions might require.

3. In the event of unavoidable loss of synchronism or an out-of-step condition, the point of separation should be restricted to the Millwood-Pleasant Valley section. If the separation should occur between Dunwoodie and Millwood, for example, it would leave the New York Edison-Niagara Hudson systems tied through the 13.8 kv network of the Westchester system which would be inadequate to hold the 2 systems in step. The result of such a contingency would undoubtedly result in tripping a large number of 13.8 kv circuits with attendant service interruptions to an important load area.

4. The substation equipment must be suitably protected against faults with the minimum number of high voltage circuit breakers.

5. In addition to the foregoing, the usual requirements for selectivity and back-up protection to the first line of defense were included in accordance with generally recognized standards for the protection of any circuit of major importance.

Short-Circuit Analysis

As the technique of fault calculations for both balanced and unbalanced conditions is well understood, no details are given here, but the results have an important bearing in 2 respects on the selection of the protective equipment which is responsive to these characteristics:

1. The magnitude of the fault currents and their variation with location and operating conditions.

2. The value of currents which flow during faults relative to those which flow during swing and out-of-step conditions.

Figures 3 and 4 show respectively the 3-phase and single-conductor-to-ground faults for average operating conditions. Similar data were calculated for 2-conductor-to-ground faults. The effect of "bussed" and separate or "unbussed" operation of the 2 circuits at Dunwoodie and Millwood were also investigated and the results plotted in a similar manner.

In connection with the first item it is interesting to note in referring to figure 3 that 2 conditions frequently encountered in relaying are both present. First, in the section between Hell Gate and Dunwoodie there is a comparatively small variation in fault current (2,000 to 2,200 amperes, curve I_H) as the fault point progresses along the circuit between these 2 stations. This practically eliminates any advantageous use of instantaneous overcurrent relays to differentiate between faults near Hell Gate and those at Dunwoodie. Second, in the section between Millwood and Pleasant Valley there is a large variation in current (curve I_L, figure 3) which could be utilized to good advantage in obtaining selectivity between overcurrent or directional overcurrent relays.

Stability calculations for loads just under the transient power limit clearly illustrate the importance of the second item, since they indicate that the line current may attain a value of 1,500 amperes, or twice the minimum 3-phase short-circuit current of 750 amperes shown in figure 3 (current I_L from Pleasant Valley for a fault near Millwood). This will be referred to later in its effect on the selection of relay equipment.

The unbalanced fault analysis data of figure 4 also were used to advantage in a parallel study of the inductive coupling between the transmission lines and communication circuits. After completion of the lines, tests were made as a check on the calculated quantities, and the results were found to be in close agreement.

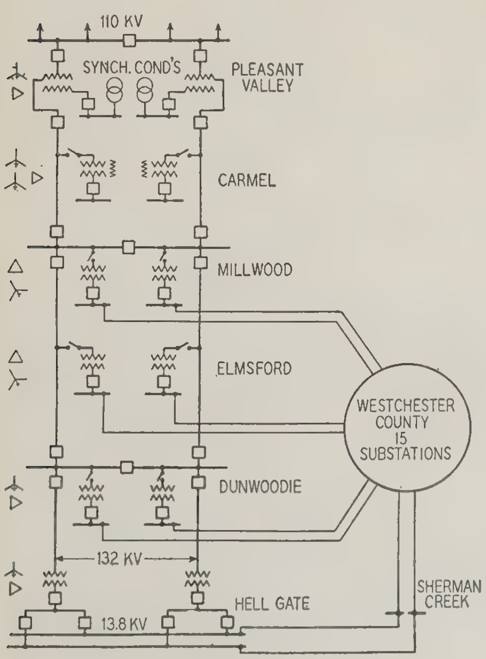


Fig. 2. Single line diagram of 132 kv circuits and the paralleling low voltage ties

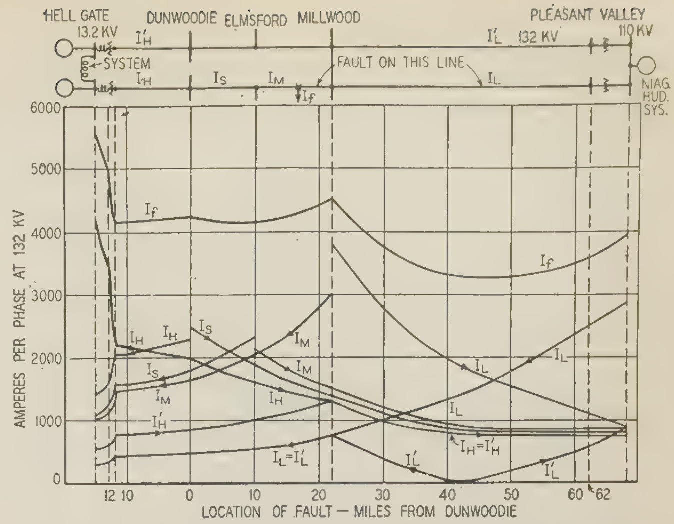


Fig. 3. Three-phase short-circuit currents. Lines "bussed" at Millwood and Pleasant Valley substations

Stability Analysis

The fault clearing time was established by a preliminary study based upon the short-circuit analysis, the use of 8-cycle circuit breakers, and conventional types of high speed relays available at the time. The characteristics of high speed distance relays and balanced current, phase, and ground relays were used for this purpose. These data were used throughout the stability studies, although the time required to clear the first circuit breaker was slightly less and the last circuit breaker somewhat greater than that attainable with the protective equipment finally adopted.

The power limits of the line were calculated for both the steady state and transient conditions and also with the circuits bussed and not bussed at Dunwoodie and Millwood. Substation loads were not taken into account in these calculations.

The calculated transient power limit with a 3 phase fault near Millwood for example, was found to be increased from 122,000 kw with separate or unbussed operation to 166,000 kw with the circuits bussed at all substations, an increase of 36 per cent. From the stability standpoint, therefore, this study definitely removed the question of the advisability of "bussing" the circuits from the realm of conjecture to the secure basis of a demonstrable fact.

With 166,000 kw established as the approximate power limit, the calculations were extended to indicate the performance at loads just over the stable limit, and also at 200,000 kw the latter figure being taken as the maximum power that might be transmitted under emergency conditions.

The quantities which were of greatest importance in the relay studies were the magnitude of the current and voltage, and their angular relation at various locations during stable swings and out-of-step conditions, and the variation of these quantities with respect to time. As indicated by item 3 of the requirements previously mentioned, it was considered essential to limit the separation of the 2 systems to the Millwood-Pleasant Valley section during out-

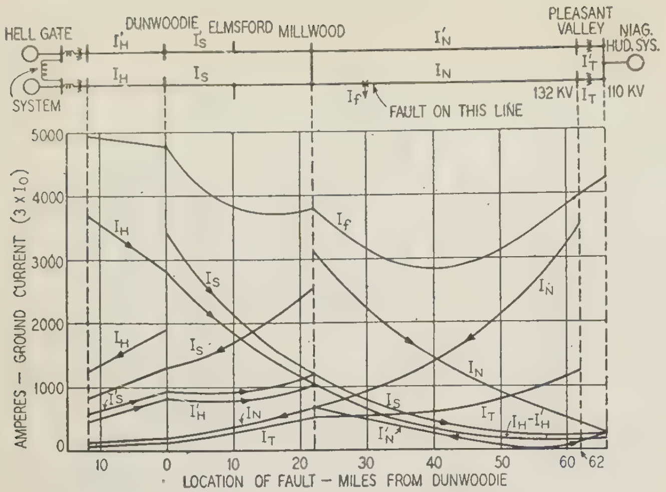


Fig. 4. Single-conductor-to-ground faults. Lines bussed at Millwood and Pleasant Valley substations

of-step conditions. The data obtained from these stability studies were invaluable for this purpose. This is convincingly demonstrated by the curves shown in figure 5.

In this case the 2 circuits were assumed to be bussed at Dunwoodie, Millwood, and Pleasant Valley, with a 3 phase fault imposed on one circuit near Millwood and a load just over the stable power limit, flowing from Pleasant Valley to Hell Gate, being carried just prior to the fault. All of the factors which affect the performance of relays are shown together with their variation with time. With data of this nature available, in conjunction with the short-circuit studies, it remained only to select or specify relay equipment which would meet specific requirements. It will be appreciated that this at once established the selection of the relays on a factual basis in which the boundaries were clearly indicated.

It was also important to determine the allowable maximum time for clearing faults from the low voltage substation busses without lowering the transient power limits of the line below those prevailing for high voltage faults. Study of this point disclosed that the most severe limitation occurred at Millwood substation. As might be expected it was found that low voltage bus faults afforded considerable latitude in fault clearing time. It was estimated that over 200,000 kw could be carried on the high voltage line for a length of time well in excess of that which would ordinarily be required for clearing such faults.

Selection of Relay Equipment

It was evident at the outset that the usual type of overcurrent relays operative on line current could not be used for 3 reasons, as follows:

1. The minimum fault current on 3-phase 2-conductor and 2-conductor-to-ground faults was in some instances less than the swing current obtainable within the maximum stable power limit, as pointed out previously.

2. Because of the small variation in fault current on some sections of the line, selectivity could be maintained only at the expense of time, but this would materially lower the maximum power limits.

3. The point of separating the 2 systems under out-of-step conditions could not be controlled.

It was realized of course that balanced current protection could be used for ground fault protection and also for phase to phase protection, since relays connected in this manner are not affected by balanced power swings. Suitable relays were available which would satisfactorily meet the operating speed requirements for maintaining the desired level of power. This form of protection, however, could not be used when one circuit of a pair was out of service, and its applicability, therefore, would be dependent upon the availability of suitable protection for single circuit operation.

The choice for single circuit protection naturally turned to distance relays of the impedance or reactance type. It was in order, therefore, to determine their performance under 3 major conditions, as follows:

1. The performance during arcing faults.

2. The performance during power swings within stable power limits.

3. The performance during power swings in excess of stable power limits.

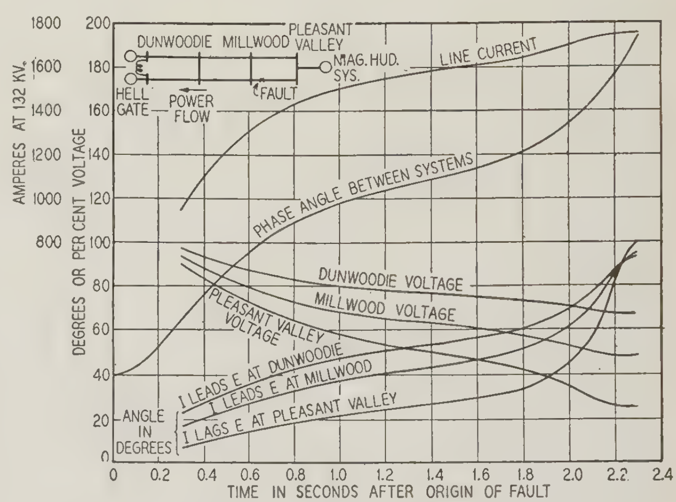


Fig. 5. Variation of line current, voltage, and angle under out-of-step conditions

Power slightly above the transient stability limit flowing toward Hell Gate prior to a 3-phase fault near Millwood on one of the Millwood-Pleasant Valley circuits. Faulted circuit cleared in 0.3 second

Possibility of Using Impedance Relays

It was concluded that no difficulty need be anticipated with impedance distance relays on the first or third steps during arcing faults since on the first step the combined relay and circuit breaker time would be in the order of 0.20 second, which would not be sufficient to introduce any appreciable arc impedance at the point of fault, and on the third step the ohm setting would be so high that arc impedance would again be of no great importance. On the second step, however, with a fault clearing of 0.50 second it was considered that even with moderately high wind speeds that there would be ample

Table I—Calculated Performance of Starting Unit of Type GAX Directional Reactance Relay During Out-of-Step Power Swings

	Relay at Millwood on the Line to Pleasant Valley				Relay at Dunwoodie on the Millwood Line			
Time After Fault Occurs	*Relay Current, Amperes	**Relay Voltage, Volts	Angle by Which Line Current Lags Line to Neutral Voltage, Degrees	Will Starting Unit Operate?	*Relay Current Amperes	**Relay Voltage Volts	Angle by Which Line Current Lags Line to Neutral Voltage, Degrees	Will Starting Unit Operate?
One Circuit Between Millwood and Pleasant Valley								
0.5	17.4	98	24	Yes	8.7	100	32	No
1.0	21.6	75	38	Yes	10.8	88	48	No
One Circuit Between Millwood and Dunwoodie								
0.3	6.7	103	17	No	13.4	108	23	No
0.4				No	15.6	103	27	Yes
0.5	8.7	98	24	No	17.4	100	32	Yes
0.9	10.6	77	36	Yes				
1.0	10.8	75	38	Yes	21.6	88	48	Yes

* Current transformer ratio—120/1. ** Potential transformer ratio—1200/1.

time for a single-line-to-ground fault to involve other conductors or possibly communicate with the other circuit. With conductor spacings of 15 feet and a 30 mile per hour wind it would require but $^1/_3$ second for an arc to travel the required distance. This factor, and also the influence of arc resistance in shifting the balance point of the relay, led to the conclusion that the reactance type distance relay was fundamentally better suited to clearing faults on the second step. It is interesting to note that subsequent to the time at which these studies were made, relays have been developed which are provided with impedance characteristics on the first and third steps and reactance characteristics on the second step.

The most serious objection, however, to the use of impedance relays was the tendency to operate at undesirable points during heavy power swings or out-of-step conditions. As the angle between the voltages of 2 generating systems increases, the voltage of all points along an interconnecting circuit gradually diminishes and at one point becomes zero when the 2 systems are 180 degrees out of phase. Where the interconnecting circuit is reactive and the terminal voltages are equal, the point of zero voltage will fall at a point midway between the 2 systems, i. e., at the reactance center of the system. It will be readily understood, therefore, that impedance relays which measure the ratio between line current and voltage, and which are located near the reactance center of the system, will receive low voltage and high current and may be expected to trip when the 2 systems are 180 degrees out of phase.

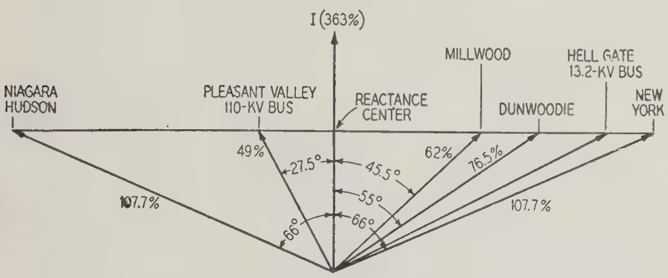


Fig. 6. Line current and voltages from figure 5 shown vectorially 1.5 seconds after origin of fault

100 per cent voltage = 132 kv
100 per cent current = 437 amperes

When one circuit between Hell Gate and Dunwoodie is out of service the reactance center of the interconnection falls south of Millwood. Tripping of the Dunwoodie-Millwood section therefore would probably occur during out-of-step swings if protected by impedance relays.

Possibility of Using Reactance Relays

Attention was next directed to the operating characteristics of reactance relays, which were considered fairly satisfactory for clearing phase faults, when connected for delta current and voltage, although as with impedance relays, open to the objection that only 80 per cent of the line at the best can be cleared on the first, or minimum time, step.

Little was known, however, in regard to their performance during swing and out-of-step conditions. A study of these relays developed that they were also quite susceptible to incorrect operation during heavy swings and during out-of-step conditions and tripping at more than one point could be anticipated. This is shown by the following analysis which was made of the type *GAX* reactance relay for this application. Reference may be made again in figure 5 showing the line current and phase angle between the 2 systems, the Millwood, Pleasant Valley, and Dunwoodie voltages and their angular positions, following a fault at Millwood on one of the Pleasant Valley lines.

In figure 6, the various quantities are shown vectorially, 1.5 seconds after the occurrence of the fault. With power flowing from Pleasant Valley to Hell Gate, the Pleasant Valley voltage leads and the Millwood and Dunwoodie voltages lag the current. For this reason, the directional starting unit of the Pleasant Valley relay is the only one that can trip, as may be deduced from figure 7, showing the pick-up characteristics of the starting element of the type *GAX* relay. As the reactance center in this case is between Pleasant Valley and Millwood and within the first step of the Pleasant Valley relay, the latter

would thus trip as soon as its starting unit closes its contacts. In this case the separation of the 2 systems would be satisfactory.

If power is flowing the other way, the Pleasant Valley voltage lags and the Dunwoodie and Millwood voltages lead the line current. The relay at Pleasant Valley would not trip under this condition. The performance of the starting units of the relays at Millwood as determined from figures 5 and 7, is shown in the upper part of table I. The reactance center is within the first step of the Millwood relay and the latter will trip as soon as its starting unit closes its contacts. In this case, the separation would take place at Millwood on the Pleasant Valley circuit and would therefore also be satisfactory. Thus, under the assumed conditions, the performance of the reactance relays on this section would be satisfactory as far as the location of the point of separation during out-of-step condition is concerned.

If, however, the fault occurs on one of the Dunwoodie-Millwood circuits, after it is cleared there will be one circuit left between Dunwoodie and Millwood, and 2 circuits between all other points. The reactance center is between Millwood and Pleasant Valley, within the first step of the Millwood relay and the second step of the Dunwoodie relay. The performance of the starting unit at these 2 stations with power flowing from Hell Gate to Pleasant Valley is as shown in the lower part of table I. It is seen from this table that the starting unit of the Millwood relay does not start until about 0.5 second after the starting unit of the Dunwoodie relay has picked up. The relay at the latter station would trip first, thus separating the 2 systems at Dunwoodie and leaving them tied through the Westchester low voltage network.

The figures in the lower part of table I are based upon the same out-of-step curves as used for the figures in the upper part of the table. This, of course, is only approximately true; but is sufficiently true to illustrate the point. The chances of the Dunwoodie relay tripping increa e, as, due to system changes, the reactance center is shifted toward Dunwoodie.

A modified design of this relay was next considered. This was arranged so that the angle between current and voltage to which it would respond was automatically shifted with time, and designed to take place during the time interval between the first and second step. Even this arrangement left such a small margin of selectivity between the relays on the Dunwoodie-Millwood section and those on the Millwood-Pleasant Valley section that it appeared extremely doubtful that the relays would operate as desired during out-of-step conditions.

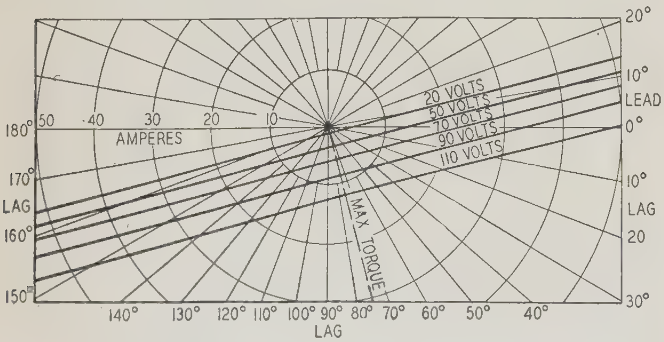


Fig. 7. Pick-up characteristics of the starting element of the type GAX directional reactance relay

The minimum operating current is plotted as a function of relay voltage and the angle between this voltage and relay current. As shown by the curve, the minimum operating current is 12 amperes at 110 volts and maximum torque angle

Carrier Current Controlled Protection

As the recently developed carrier current control system of protection seemed to offer considerable promise the study was extended to include this type of equipment. It may be well to note that the title accurately denotes the operating principle, for the function of the carrier signal is not to operate the protective relays directly but to control their operation by means of carrier operated blocking relays connected in the trip circuits of the protective relays.

While several modifications of this protective scheme are possible, 2 of them are basic:

1. The protective relays are free to trip when no carrier signal is transmitted.
2. The protective relays can trip only when the carrier signal is transmitted.

In this case, the first alternative was selected as being the most desirable. When the fault is on the protected section no carrier signal is transmitted and the relays are free to trip. Failure of the carrier channel or equipment does not therefore interfere with clearing the fault. Failure of the carrier signal during faults on other parts of the system can only mean that the relays are tripped unnecessarily but this is considered to be far less undesirable than failure to trip when essential.

In general, the relay equipment consists of carrier current controlled directional overcurrent protection for phase to phase faults and directional ground protection at the terminals of each high voltage circuit. The operating principle of the carrier current control will be understood by referring to figure 8, showing the principal control elements. The directional overcurrent protection is provided by a polyphase power directional relay (3) in combination with 3 special induction type overcurrent relays (2) and 3 high speed solenoid type overcurrent relays (4).

Power directional relay (3) is provided with a potential restraint which holds the relay contacts closed under normal conditions of power flow in either direction. When a fault occurs, high speed relays (4) operate to remove the restraint in less than one cycle. This arrangement materially increases the speed and sensitivity of the power directional unit. When fault current flows toward the bus, the contacts of the power directional relay open, removing the negative bias from the grid of the transmitting oscillator, thereby starting carrier transmission at once, thus blocking tripping action at the other end of the protected section by opening the receiver relay contacts at that point, and at the same time blocking the tripping action of overcurrent relays (2) at the local station.

Directional ground protection controlled by carrier

current is provided by 2 directional ground relays. The carrier starting relay (5) opens its contacts when fault current is flowing toward the bus and removes the negative bias from the grid of the transmitting oscillator. The tripping directional ground relay (7) is provided with 2 sets of contacts, one set for tripping and the other set, normally closed, in the plate circuit of the master oscillator. The purpose of the latter is to insure that the ground relays will take precedence over the power directional relays with a phase to ground fault on the protected circuit. This arrangement prevents the possibility of the power directional relay starting the carrier current with a heavy flow of power toward the bus at the time of a phase to ground fault on the protected circuit.

The back-up, directional overcurrent ground relay (9) operates independently of the carrier current control and is connected to an independent set of current transformers. This ground relay as well as those controlled by the carrier current is polarized by zero sequence potential derived from bushing potential devices at Dunwoodie and Millwood. The corresponding relays at Pleasant Valley are polarized by the power transformer neutral current.

The definite time back-up relay (10) is used as a protection against switch failure. As indicated in the diagram, the relay is connected in parallel with the trip coil and trips out all other circuits capable of supplying current to the fault, by means of the multi-contact tripping relay (11).

Each section of the transmission circuit is tuned to a different frequency for carrier current transmission to avoid any possibility of false operation, although the range to which the carrier equipment on any section is resonant is confined to a band of approximately 10 kilocycles. Frequencies employed fall within a range of 50 to 150 kilocycles.

When a phase to phase fault occurs on the protected section the fault current flows away from the bus at the 2 terminal points toward the fault. The restraint is removed from the power directional relays (3), which are, however, held in their closed position by the fault current and maintain through their contacts a strong negative grid bias on the transmitting oscillator, preventing the transmission of carrier signals. The receiver relays (1) remain closed, thus maintaining the trip circuit for the tripping relays (2) which act after approximately 0.10 second to clear the fault.

When the phase to phase fault is outside the protected section, overcurrent relays (4) at both stations operate as before to remove the restraint from the power directional relays. But, in this case, the power directional relay at one station opens its contacts starting a carrier signal which operates the receiver blocking relays thus opening the trip circuits before the tripping relays can close their contacts. After the fault is cleared the various relays reset in the proper sequence to prevent false tripping. The necessary selectivity of the resetting action is obtained by introducing a slight time delay in the closing of the power directional and receiver relays after the fault is removed. The directional ground relays operate in a similar manner for ground faults.

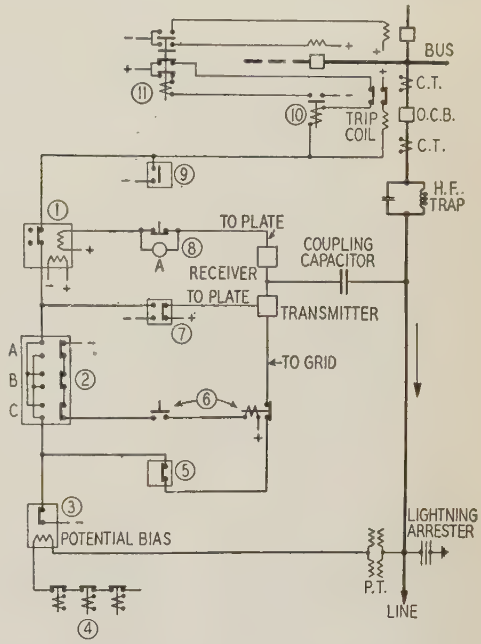
The selectivity on the blocking and resetting operations is illustrated in figures 9*a* and 9*b*, respectively, which show typical tracings of oscillographic timing tests.

Carrier Current Control During Swing and Out-of-Step Conditions

It was still necessary, however, to check the performance of the power directional relays during swing and out-of-step conditions, even with the carrier control, as there was no assurance that tripping could not take place on 2 different sections of the line, or that it would take place at the desired points.

Fig. 8. Simplified diagram of control circuits of relays for carrier current controlled system used with one 132 kv oil circuit breaker

All relay contacts shown in normal position. Arrow shows direction of power in high voltage line to close relay contacts which are normally open, and to open contacts which are normally closed



1. Receiver relay
2. Phase overcurrent tripping relays
3. Power directional relay for starting carrier signal
4. Instantaneous overcurrent relays
5. Directional ground relay for starting carrier signal
6. Push button and contactor for starting carrier test signal
7. Directional ground tripping relay
8. Push button and ammeter for measuring receiver current
9. Back-up directional ground relay. Independent of carrier
10. Definite time back-up relay
11. Hand reset tripping relay

It was found that with all of the power directional elements set alike on timing, and responsive to their maximum torque position at the same angle, the relays on the Millwood-Pleasant Valley section would have insufficient time to trip during out-of-step conditions.

Two means are readily available for suitably modifying the characteristics of the power directional relays: (*a*) Time adjustment; and (*b*) torque angle adjustment.

The carrier current control, as used in this installation, is eminently adapted to the introduction of time selectivity between the power directional relays. As the contacts of the power directional relays are normally closed, the resetting time after an opening operation may be delayed without increasing the time required to clear a fault on the protected section. During out-of-step power swings

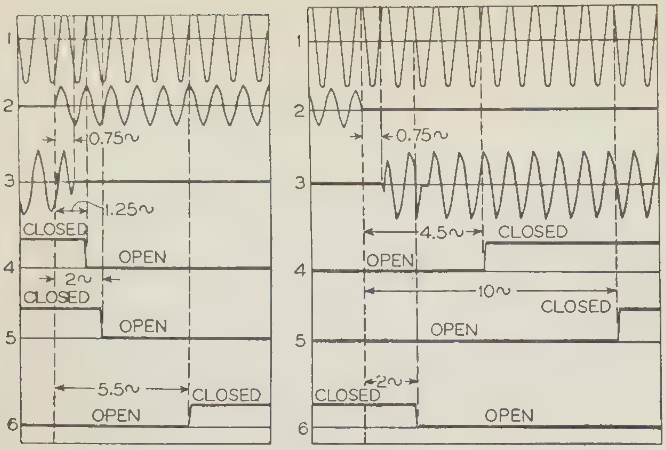


Fig. 9. Test showing time selectivity of blocking operation (left) and of resetting operation (right) of carrier controlled phase relays when fault is outside of the protected section

Fig. 9a (left)

1. 60 cycle timing wave
2. Operating current (12 amperes) applied
3. Voltage restraint removed from power directional relays
4. Power directional relay contacts open, starting transmission of carrier signal
5. Receiver relay contacts open oil circuit breaker trip circuit
6. Tripping relay contacts close

Fig. 9b (right)

1. 60 cycle timing wave
2. Operating current (12 amperes) interrupted deenergizing power directional and tripping relays
3. Voltage restraint applied to power directional relays
4. Power directional relay contacts close, stopping transmission of carrier signal
5. Receiver relay resets, reëstablishing oil circuit breaker trip circuit
6. Tripping relay contacts open

with the power flowing in one direction, half of the power directional relays will open their contacts and transmit the lock-out carrier signal. When the power flow reverses in direction the delayed time in the resetting of these relays will afford ample time for the relays at the opposite end of the line to open their contacts and continue the transmission of the signal. This action in maintaining a continuous transmission of the carrier signal prevents tripping the switches at both ends of the section.

The torque angle adjustment provides a further means of adjusting the operating characteristics of the power directional relays on the different sections of the transmission circuit by virtue of the different angular relations which may prevail between voltage and current, and the variation of these quantities with time as the power swing progresses. For example, if the relays on the line section which it is desired to trip under out-of-step conditions are adjusted to have their maximum torque while those on the remaining sections are adjusted to have a smaller torque at the voltages, currents, and angles prevailing on the respective line sections, a still greater degree of selectivity may be attained.

It may not always be possible, however, to modify the relay operating characteristics so that the desired performance can be realized on the particular section which it is desired to trip under out-of-step conditions. In such cases it would be desirable to provide special out-of-step relays which operate on the first swing which passes through an angle in excess of 180 degrees, to trip the desired section of line and lock out all other sections. In this instance it was found feasible to modify the power directional relay characteristics by the methods mentioned, to an apparently satisfactory degree. A clearer understanding of the method employed may be had by referring to figures 10 to 12.

Application to Pleasant Valley-Dunwoodie Sections

Figure 10 shows the conditions calculated for the Millwood-Pleasant Valley section. The vector diagram inserts show the operating angle of the power directional relays at the 2 line terminals as adjusted by potential phase shifting transformers. It will be observed, for example, that the contacts of the Pleasant Valley relay are closed (no carrier signal transmitted) when the position of the line current with respect to the line to neutral voltage varies through an angle of 140 degrees lag to 40 degrees lead while the corresponding angles for the Millwood relay are 124 degrees lag to 56 degrees lead.

The dotted curve shows the angular relation between line current and voltage when the power being transmitted from Pleasant Valley to Hell Gate is just within the transient stability limit (166,000 kw) with a 3-phase fault on one circuit near Millwood. This angular relation is plotted against time, measured from the instant of fault, and assumes the faulted circuit to have been cleared in 0.30 second.

While the Pleasant Valley relay remains in the closed (tripping) position at all times, the Millwood relay is always in the open position, since the line current never lags its voltage by less than 140 degrees whereas this relay cannot operate unless the angle of lag is less than 124 degrees. In this diagram the line current for the Millwood relay is reversed by 180 degrees from its true position in order to show its phase position as "seen" by the relay.

The solid curve shows similar conditions except in this case the power just prior to the fault is just sufficient to throw the 2 systems out of synchronism. The Pleasant Valley relay remains in the closed position for 2.52 seconds. The Millwood relay enters the tripping range after 1.9 seconds, so there is an interval of 0.62 second in which both relays are in the closed position, which is more than ample time to permit tripping the circuit.

Referring next to figure 11, the effect of the same fault and swing on the relays of the Millwood-Dunwoodie section is shown. It will be observed that the relays at both of these points are adjusted for an operating angle of 105 degrees lag to 75 degrees lead. The relays on this section were given the time delayed action in resetting, although this is not illustrated here. At no time are the relays at the 2 line terminals in the tripping range at the same time for 166,000 kw; and for a period of only 0.04 second—or insufficient to cause tripping—during out-of-step conditions.

Similar curves for the Millwood-Pleasant Valley section except for 200,000 kw power transfer are shown in figure 12. While this represents an emergency condition which may seldom, if ever, be en-

countered in actual service, it shows that both relays are in the tripping position for 0.15 second. The chances of effecting the desired tripping are indeed reduced to a very small margin. In this case the stability calculations were carried out to include the second swing. This illustrates the necessity of tripping on the first swing, as the period of the swings becomes faster with elapsed time.

The most unfavorable cases have been shown, since power limits above the normal line ratings have been used in conjunction with 3-phase faults. Operating experience on similar circuits has shown that only a small percentage of the faults are 3 phase. Single conductor and 2-conductor-to-ground faults, of course, provide a wider margin of stability reserve than 3-phase faults for the same amount of power transfer, and the rate at which the 2 systems would approach their maximum angular positions would be correspondingly decreased.

Protection of Dunwoodie-Hell Gate Section

While it was not considered feasible at this time to transmit carrier frequency over the 12 mile section of the 132 kv underground cable circuits between Hell Gate and Dunwoodie, this did not prove to be a serious handicap. This section of the circuit is

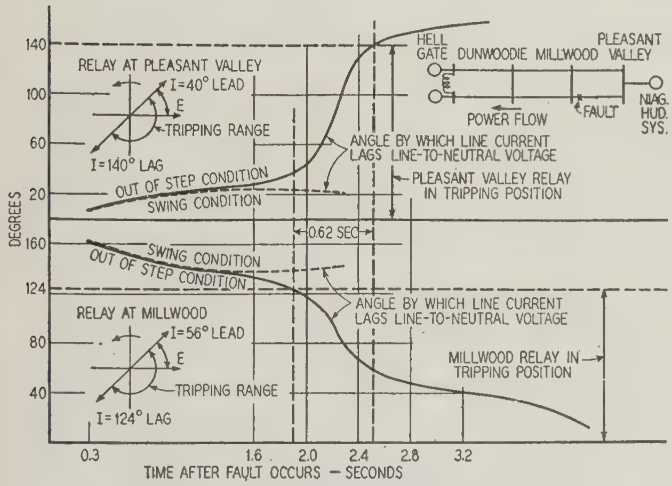


Fig. 10. Angular relation between line current and line to neutral voltage plotted as a function of time during swing and out-of-step conditions for the Millwood-Pleasant Valley section, after tripping one circuit on a 3-phase fault near Millwood

The vector diagram insert shows the tripping range of the power directional relays at Millwood and Pleasant Valley, I representing the line current and E the line to neutral voltage. Power for the "swing" condition is just within the stable power limit but slightly over the stable power limit for the out-of-step condition. The relays on the Millwood-Pleasant Valley section are in the trip position for 0.62 second at both stations during the out-of-step swing

contiguous to one end of the interconnection and the major portion of the impedance is lumped at the generating station terminus, a condition favorable to the use of standard relay equipment.

As shown in figure 2, 2 automatic circuit breakers are in series between the generating station bus and the step-up transformers—the standard switching equipment for all outgoing circuits at this station. No automatic circuit breaker is used on the high voltage side. Each 100,000 kva transformer bank is composed of 2 banks, one being of 3-phase construction and the other consisting of 3 single phase units. The 132 kv cable from the high voltage

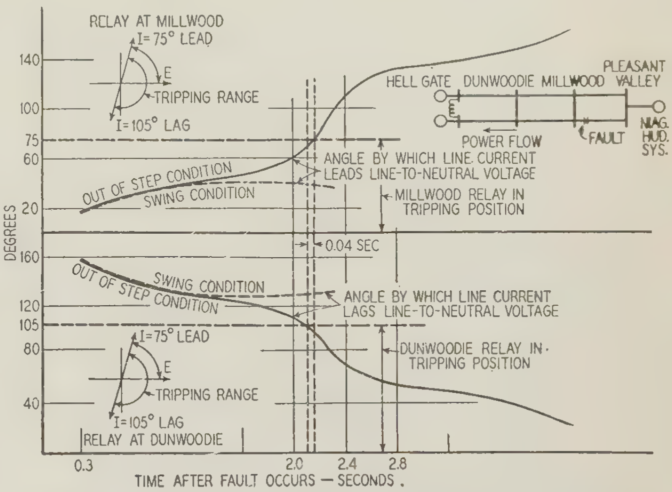


Fig. 11. Angular relations between line current and voltage on the Dunwoodie Millwood Section for the same conditions shown in figure 10

On this section, however, both relays are in the trip position for only 0.04 second, which is insufficient to permit tripping

transformer terminals to the bus at Dunwoodie is single conductor with one conductor per duct, connecting to an automatic circuit breaker at Dunwoodie.

Simple overcurrent ground relays and differential relays were used for the primary protection from the 13.8 kv switch to the high voltage transformer terminals. The 132 kv cable itself was protected by overcurrent ground relays connected in the transformer neutral circuit at Hell Gate and directional ground relays at Dunwoodie. These relays are not affected by balanced power swings. The principal problem was to provide back-up protection, for both relays and switches, which would also be immune from incorrect operation during power swings.

At Hell Gate, back-up ground relay protection for the 13.8 kv connections was provided by the addition of another overcurrent ground relay supplied from a separate set of current transformers and connected to trip the bus selector switch. Since the reactance center of the system was calculated to fall well north of Dunwoodie except under very abnormal operating conditions, it was clear that directional distance relays of the reactance type could be used as a back-up to the Hell Gate transformer differential relays, provided the setting point was limited to a point corresponding to a 3-phase fault only slightly north of Dunwoodie. In addition, therefore, these relays also protect against single-conductor-to-ground faults for a portion of the cable circuit and against phase to phase faults for the entire length including the 132 kv bus at Dunwoodie. Both the

first and second steps of the relay were used to cover the protected section but the third or definite time back-up step was omitted.

Since it was planned to omit high voltage circuit breakers at Hell Gate it was desirable to provide relays at Dunwoodie which would clear phase to phase faults in the transformers at Hell Gate. Directional distance relays of the reactance type were used for the purpose, omitting the third or definite time back-up step, as at Hell Gate. While the required ohm setting of these relays is higher than the reactance measured during out-of-step swings, the relay should never operate under such conditions for 2 reasons:

1. The directional relay element is inoperative when the relay current with respect to the voltage falls within an angle varying from 15 degrees lead to 165 degrees lag. When the power flow is toward Hell Gate the relay current leads the voltage by an angle varying from zero degrees to 90 degrees lead. The relay is in the operating range, therefore, only between zero degrees and 15 degrees lead, but the current is insufficient to cause operation at the voltages prevailing.

2. When the power flow is away from Hell Gate, the current leads the voltage by an angle varying between 90 to 180 degrees lead, since the reactance center of the system is normally north of Dunwoodie. This again represents an inoperative condition for the relay.

These facts may be deduced by comparing the operating angles of the relay shown in figure 7 with the curves given in figure 5, keeping in mind that the

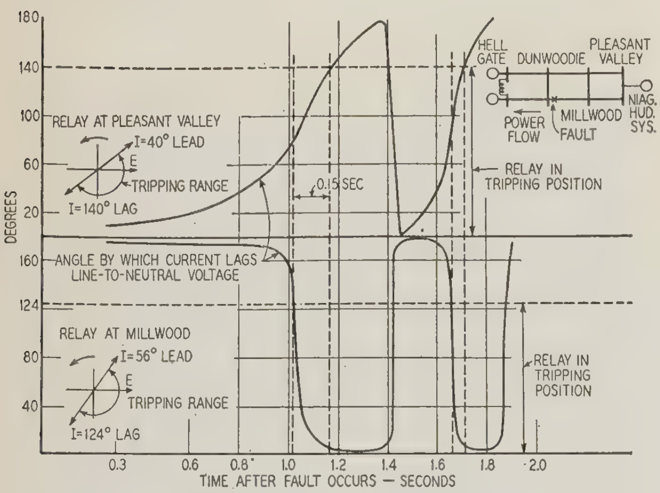


Fig. 12. The same section of line as shown in figure 10, except that the power being transmitted prior to the fault is increased to 200,000 kw or well over the transient power limit for a 3-phase fault at the point shown

The time available for the relays to trip at Millwood and Pleasant Valley is reduced to 0.15 second

relay current transformers are connected in delta in such a manner that the relay voltages are in phase with the corresponding line currents at unity power factor.

Protection at Substations

At Dunwoodie no high voltage circuit breakers were provided for the transformer banks, and no facilities were readily available for mounting current transformers for use with transformer differential relays since current transformers had not been originally provided on the bushings of the existing transformer banks. This protection was provided by adding a scheme of 3 phase overcurrent protection to the 132 kv bus differential circuit—in effect an incomplete bus differential scheme. These relays are provided with instantaneous overcurrent elements to protect against line to line high voltage bus short circuits, and with time delay elements for protection against phase to phase faults in the transformer windings and on low voltage leads.

The 132 kv bus differential ground relays at this substation, as in all others, will operate in 1 to 2 cycles. The pick-up current is set above the normal load currents, to prevent false operation during switching operations.

At Elmsford, the step-down transformers were delta connected on the high voltage side and no high voltage switches were provided. A time delay, zero sequence voltage relay, connected to bushing potential devices, is used to trip the low voltage circuit breakers for 132 kv line to ground faults, as otherwise the line would remain alive until switched manually.

The protection at Millwood is quite similar to that at Dunwoodie. In this case the substation transformers were purchased coincident with the remaining equipment and the high voltage terminals were provided with bushing current transformers. It was possible, therefore, to provide complete transformer differential protection.

At Pleasant Valley the chief difference from the protection used at other points lies in the use of 2 sets of definite time back-up relays, one for the line circuit breaker and the other for the transformer differential and the use of transformer neutral current for polarization of the directional ground relays.

Usual Type of Back-Up Protection Omitted

From the brief description of the protective devices employed it is apparent that a radical departure from common practice has been made by the omission of any type of overcurrent relays operative on line current for back-up protection. This was essential if control of the point of separation under out-of-step swings was to be realized. The justification for this procedure was based upon the following premises:

1. While phase to phase faults not involving ground on the overhead open wire lines are possible, the use of 3 single pole elements for the tripping relay of the carrier controlled equipment is considered to provide a reasonable degree of protection against failure of the relay equipment.

2. Failure of the carrier signal or the relays controlling its transmission does not prevent tripping the faulted section. This does not, of course, protect against failure of the tripping supply, but the reliability of this source is so high that failure may be said to be practically unknown. This hazard, if it may be considered as such, is no greater than the same hazard which exists in generating stations where it has been general practice for many years to provide one tripping source and where the required degree of reliability is higher than in most substations.

3. Protection against circuit breaker failure has been provided for by the use of a d-c definite time auxiliary relay which is energized when the trip coil is energized. If the fault is not cleared by the

circuit breaker on the faulted circuit, this relay acts after a definite time interval to trip off all other circuits capable of supplying fault current.

4. An hourly check of the carrier equipment and a monthly operating check of circuit breakers and inspection of relays is calculated to uncover any defects which are likely to occur in this equipment and to insure its maintenance at a high level of efficiency and reliability.

Operating Experience With Carrier Current Equipment

The complete interconnection with carrier current control protection of the overhead sections was placed in service May 1, 1933, although part of the line was in operation prior to this date. The operating experience cited here covers approximately one year's time, subsequent to placing the equipment in service.

The chief trouble experienced with the carrier current equipment occurred during the period of unusually low temperatures experienced in January and February 1934, when the hourly checks on carrier signal strength revealed an alarming reduction in signal strength during the low temperature periods. After an operating check of the terminal equipment it was concluded that the trouble probably lay in the line traps. This was confirmed by a separate check made by the manufacturer. The cause was found to be a change in capacitance of the line trap condensers at low temperatures. These condensers were replaced by others with a mica dielectric which eliminated further troubles of this nature.

Trouble was also experienced by the receipt of very short stray signals. This was ascribed to insufficient wipe in the normally closed contacts of the relays which control the negative grid bias circuit of the transmitter. A slight readjustment of the relay contacts was sufficient to eliminate most of this trouble.

In some instances when one of the 132 kv circuits was switched out a short carrier signal was transmitted. The cause for this has not been definitely determined but possibly may have been caused by the momentary removal of restraint from the power directional relays.

The operating performance of the various tubes used with the carrier current receivers and transmitters is summarized in table II. The average life does not, of course, represent the time that the tubes are receiving or transmitting signals, since this is limited to a few seconds per hour, but rather represents the number of days in service.

Automatic Operations

During the 16 month period from May 1, 1933, to September 1, 1934, a total of 40 electrical storms were encountered, as recorded by the station logs at Millwood and Pleasant Valley; trip-outs resulting on 3 occasions. This affords a measure of the effectiveness of line insulation and relay protective equipment against lightning. In one instance the fault involved both circuits of the Millwood-Pleasant Valley section. The relay target devices indicated that the fault occurred on the same phase on both lines, but as insufficient evidence of arcing precluded the location of the fault it was not possible to determine the relative position of the 2 line conductors involved. One other fault, not caused by lightning, involved all 3 phases on one circuit and was cleared by the protective equipment. To date, no incorrect relay operations have occurred during faults on the 132 kv circuits nor has there been any instance in which the relays have operated incorrectly as a result of numerous faults on the lines north of Pleasant Valley, or on feeders from Hell Gate station.

Table II—Performance of Carrier Equipment Vacuum Tubes, May 1, 1933 to August 13, 1934

	Type 83 Rectifiers	Type 210 Receiver and Oscillator	Type 210 Amplifier	Total
1. Number in service	8	16	8	32
2. Average life—days*	211	296	272	
3. Number of failures				
(a) Emission test	10	9	5	24
(b) Filament burn-out	0	1	0	1
(c) Other causes	1	0	0	1
Total failures	11	10	5	26
4. Failures detected on				
(a) Monthly emission tests	7	5	5	17
(b) Hourly push button test	4	5	0	9
	11	10	5	26

Tubes are rejected when they fail to meet the following tests:
(a). *Type 83. Rectifier Tubes.* With filament preheated for 20 minutes at 5 volts alternating current, and 400 milliamperes d-c plate current, drop from anode plate to filament shall not exceed 20 volts.
(b). *Type 210. Receiver and Oscillator.* With plate and grid terminals connected together, filament excited at 6 volts alternating current and 125 volts direct current applied between plate and filament, plate emission shall be over 50 milliamperes.
(c). *Type 210. Amplifier.* Same as test (b) except plate emission shall be over 100 milliamperes.
* Applies only to tubes which have failed.

In all 3 instances where trouble occurred on the 132 kv overhead sections as a result of lightning, the damage to the line was so slight that the fault location could not be ascertained by careful inspection. This is perhaps the most convincing demonstration that could be presented of the effectiveness of high speed protection in limiting damage to the equipment.

No clear cut case of instability has occurred to demonstrate the effectiveness of the relay equipment in separating the 2 systems at the desired points. On one occasion, however, a close approach was apparently made. In this instance a number of circuits north of Pleasant Valley tripped off during a lightning disturbance in that area. There were a number of heavy swings on the tie lines which the operator at Pleasant Valley considered to be sufficient indication of out-of-step operation. One of the Millwood circuits was disconnected manually at Pleasant Valley and at the instant that the second Millwood line was switched out, it opened automatically at Millwood.

An automatic oscillograph has since been installed at Pleasant Valley, and although sufficient elements are not available to record all of the desired quanti-

ties, more definite information than that ascertainable by the usual indicating and recording instruments will be available in the future.

MAINTENANCE

The carrier equipment is checked hourly by the substation operators and readings of carrier signal strength noted on ammeters connected in each receiver relay circuit. The test is quite simple and can be completed in a very short interval, since it requires only the pressing of a button to transmit the signal, and the reading of an ammeter.

A code signal is used to identify the line being tested, and by means of a prearranged schedule, the initiating station transmits a warning signal and receives a "ready" signal by the receiving substation. Signals of approximately 2 seconds' duration are then transmitted by the initiating station and answered by the receiving station, thus permitting a check of signal strength of each circuit at each substation.

Poor condition of any of the tubes is usually indicated by a gradual decrease in signal strength as recorded by several successive hourly tests. About 30 per cent of the failures have been detected on these tests.

At monthly intervals a complete check is made of all tubes by means of a portable test set. At the same time all 132 kv circuit breakers are tripped by the relays to insure that all electrical and mechanical devices are in proper working condition.

At periodic intervals a complete calibration test is made of all line protective relays. As the time settings are very short and the selectivity between various relays is in the order of a few cycles, special high speed timing devices are used for this purpose.

At Pleasant Valley the automatic oscillograph is used for checking the timing of the relays after they have been individually calibrated. The record shows the performance of the combined relay installation, including the time margins between starting of the carrier signal and individual relay tripping and resetting operations.

At other substations an electronic timer is used for checking the calibration of the individual relay units.

Surge Currents in Protective Devices

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Lightning arresters are expected to protect equipment against damage and outage from lightning, and to have an economical life. In order to accomplish these ends effectively, arresters should be able to discharge all surge currents whose probability of occurrence is such that the average life of the arresters will be in an economic balance with their cost. In this paper existing data have been assembled and analyzed in an effort to determine the magnitude of these impulses and the probable frequency of their occurrence.

THERE has been much discussion in the past concerning the principles of operation under which various devices developed to discharge lightning surge currents from transmission lines operate to perform their function, and a great variety of data have been presented to show what may be expected from such devices under given sets of conditions; but information regarding the magnitude of impulse currents these devices may be required to discharge under operating conditions, and the probable frequency of occurrence of these impulses is by no means as plentiful. There has been further discussion, and criticism, of the impulse test in the proposed lightning arrester standards of the A.I.E.E. as falling short of the requirements for certain applications, without convincing data as to the duty to be encountered. In this paper the factors involved are discussed with a view to rationalizing the problem.

It is concluded that lightning disturbances other than those following a direct stroke or streamer to the transmission line impose no very severe duty on the protective device. Direct strokes or streamers to the line at some distance from the device are transmitted to it in the form of traveling waves, the characteristics of which are limited by the minimum flashover voltage to ground of the line itself. Under these conditions the duty imposed on the protective device is moderate and in reasonable agreement with the tests required by the proposed A.I.E.E. standards. The more infrequent direct strokes to the line in the immediate vicinity of the arrester are not necessarily limited by line insulation characteristics and may reach very much higher surge current values.

A paper recommended for publication by the A.I.E.E. committee on protective devices, and tentatively scheduled for discussion at the A.I.E.E. summer convention, Ithaca, N. Y., June 24–28, 1935. Manuscript submitted Oct. 15, 1934; released for publication Nov. 5, 1934.

Various factors governing the discharge of surge current from distribution lines permit of relatively high current values in this class of service as well.

Concerning the frequency of occurrences of these high current surges, present available data indicate the probability of a disturbance involving surge currents of from 5,000 amperes upward, once for every 10,000 to 20,000 feet of exposed line per year. These currents will range up to values in the order of 100,000 amperes with the higher currents occurring least frequently. Since these maximum currents affect only devices within 250 feet of the origin of the disturbance on distribution circuits, the probability of any one set of devices being subjected to a high current operation is once in 20 to 40 years, or conversely one set out of 20 to 40 installed may be subjected to one high current operation each year.

In the present state of the art the full discharge capacity, 100,000 amperes, indicated as necessary if an arrester is to be good for all conditions, cannot be provided without exceeding economic limitations or sacrificing protective ability. The very infrequent occurrence of currents high enough to cause failure of present types of arresters good for limited discharge capacity makes it appear poor economy to sacrifice in either cost or protective ability for higher current capacity. In special cases where the penalty of failure is greater and where the protection requirements are less rigid, a device capable of withstanding the maximum discharge to be expected may be employed.

General

The current to be discharged through a lightning arrester is dependent on several factors such as: the impulse voltage impressed on the line; the distance between the arrester and the point at which the impulse originates; the impedance of the arrester ground; and, to a small degree, the characteristics of the arrester itself. The duty imposed on an arrester by induced voltages such as that caused by a discharge from cloud to earth near by, but not terminating on the line, is relatively light and, for the purposes of this discussion, may be neglected. There remains then for consideration only the direct stroke which terminates entirely or in part on some portion of the line.

The probability of a severe direct stroke on the arrester itself appears relatively remote and may also be neglected since present types of lightning arresters generally are not designed to afford protection against such a stroke. This leaves then 2 major classifications of disturbance to be dealt with, namely: (1) direct strokes to the line at some distance from the arrester, producing a traveling wave that approaches the arrester over the line; and (2) direct strokes to the line close to the arrester. It will be apparent that with the present practice of installing arresters relatively far apart (as compared with the span lengths of a line), the probability of a direct stroke occurring within 1 or 2 spans of an arrester is much less than that of its occurrence outside that region; therefore, a large proportion of arrester discharges will result from disturbances under class 1, that is, as the result of a traveling wave.

Traveling Waves

The maximum impulse voltage that can be transmitted along an overhead line is limited to the impulse flashover voltage from that line to ground, and is roughly proportional to the minimum striking distance from the line conductor to the nearest grounded object on the structure. For steel towers the flashover voltage will be determined by the characteristics of the insulator string, provided that the clearance from conductor to tower is not less at some other point. On wood pole lines the insulator strings ordinarily are supported by wooden crossarms which, together with the pole itself, form a longer insulating path to ground and raise the impulse flashover voltage above that of the insulator string alone. The presence of guy wires on any wooden pole of a line must be taken into consideration, however, since they will shorten the path to ground very materially and thus be a governing factor in determining the impulse flashover voltage. Several papers have been published giving detailed data concerning the impulse flashover characteristics for different types of line insulation.[1,2,3,4,5] For applications in which specific data are not available, a reasonable approximation may be arrived at by using as the minimum voltage required to flash across

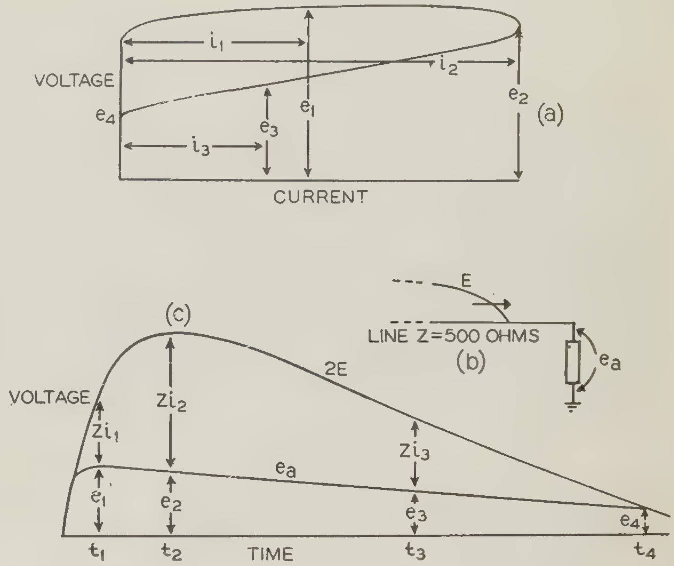

Fig. 1. Development of the equivalent transmission line curve (c) from the volt-ampere curve (a) under the conditions given in (b)

At any instant the arrester voltage plus the iZ potential drop in the line equal the doubled traveling wave voltage

$$i_a = \frac{2E}{Z_1 + Z_a} \tag{1}$$

$$i_aZ_1 + i_aZ_a = 2E \tag{2}$$

$$i_aZ_1 + e_a = 2E \tag{3}$$

1. For all numbered references see list at end of paper.

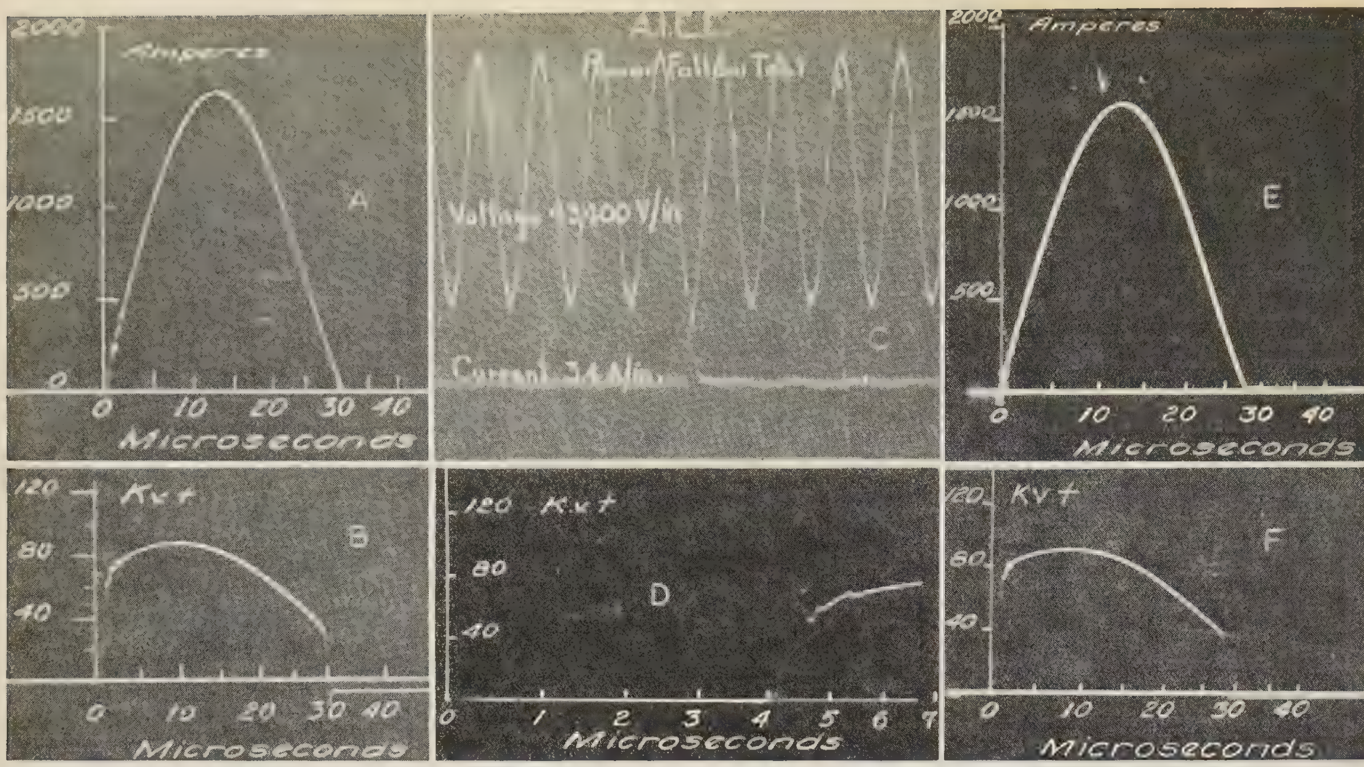

Fig. 2. Test records of the recommended A.I.E.E. standard impulse and operating cycle tests on a 25 kv station type arrester

A, B, and D. Ampere-time and volt-time curves of impulse test before operating duty test
C. Magnetic oscillogram taken during one of 30 operations with combined 750 ampere impulse and 24 kv power voltage.
E and F. Impulse test records after operating duty test

a clear air gap with a 1.5 x 40 microsecond positive impulse wave, a value of 16 kv crest per inch of striking distance and a value of 12 kv crest for creepage over wood alone. This minimum flashover voltage is usually greater for negative waves and is always greater for shorter waves.

Now, a traveling wave of voltage e on a line of surge impedance Z is accompanied by a surge current of the value $i = e/Z$. The surge impedance of the average overhead line may be assumed to be of the order of 400 to 500 ohms. In order to limit the traveling wave voltage from line to ground at the end of a line, the protective device must discharge a current of from 1 to 2 times the traveling wave current as determined by the formula given in the caption of figure 1. In effect, the protective device reduces the surge voltage by drawing current through the line surge impedance. These general relationships may be applied to any protective device or system such as an air gap, resistor, capacitor, cable, deion protector, or a lightning arrester.

In table I are shown representative data for various voltage ratings, showing the currents in crest amperes that the arrester will be required to discharge in the most usual class of disturbance, i. e., a direct stroke at sufficient distance to result in a traveling wave from the origin of disturbance to the arrester. These currents are based upon limitation of the traveling wave voltages by the minimum flashover clearances from line to ground shown in the table. Under these conditions and for an arrester voltage ratio of 2.5, the current discharge on a long positive wave cannot exceed the values in the third column of the table. For a wood pole line, designed to secure maximum use of the wood for impulse insulation, the traveling wave voltages and corresponding currents may be greater.

In recognition of the fact that the function of a lightning arrester is to limit surge voltages by discharging current when subjected to a traveling wave, the proposed lightning arrester standards of the A.I.E.E.[6] include a representative impulse test to determine the performance of the device. This test may be summarized as follows:

> The applied test impulse shall rise at 100 kv per microsecond per 11.5 kv of arrester rating. After the arrester begins discharging, the current shall rise to crest value in 10 microseconds and fall to half value in not less than an additional 10 microseconds. The specified crest value of current is 1,500 amperes for both line type and station type arresters.

Figure 2 shows records of a test made as required by the proposed A.I.E.E. impulse and operating duty cycle tests on a 25-kv station-type arrester. This

Table I—Approximate Maximum Surge Currents Through an Arrester at the End of a Line, Where the Traveling Wave Is Limited by Line-to-Ground Flashover

System Voltage, Kv	Minimum Surge Flash-over Distance, Line-to-Ground, Inches	Crest Arrester Current, Amperes
2.3	12	800
13.8	20	1,200
24	24	1,350
69	36	1,700
115	42	1,750
138	52	2,170

laboratory impulse test is the equivalent of an operation in service by a traveling wave of the shape and magnitude shown in figure 3 and derived by equation 3, figure 1. On this test the arrester reduced the 850 kv, which otherwise would have appeared at the open end of the line, to 90 kv. It may be noted that the proposed A.I.E.E. tests for arresters are in close agreement with the current values shown in table I.

Direct Strokes

Turning now to the second and less usual class of disturbances, that in which a direct stroke or streamer thereof terminates on the line in the immediate vicinity of an arrester, limitations of line insulation are not an important factor in determining the value of current that must be discharged. In this case the maximum current is determined by the characteristics of the stroke or streamer itself, and the principal source of information concerning these characteristics is data from field measurements on, and operating records of, transmission lines in service. Such measurements as have been made in the field and published[7,8,21] showing the order of current values caused by direct strokes to transmission lines, indicate that they may reach a maximum of 100,000 amperes.

Other sources of data give an indication of the probable frequency of occurrence of surge currents above a certain minimum value. These are the records of lightning flashover on transmission lines with known insulation characteristics. A streamer terminating on a line transmits a voltage surge in the form of a traveling wave in both directions from the point of contact. Following the procedure previously set forth in this paper for determining the current accompanying a traveling wave, the flashover voltage of the line divided by half the surge impedance of the line, say 250 ohms, is a measure of the total current from the streamer into the 2 surges, one in either direction. Where protective devices of the gap type are applied to prevent all line-to-ground flashovers on a high voltage line, the devices must discharge substanially full surge current to ground either individually or in parallel. More often, probably the 2 devices nearest the stroke divide the current roughly between them.

In table II are listed certain overhead transmission lines with their published flashover records stated in terms of flashovers per hundred miles of lines per year. From such data as have been published, the author also has tabulated (1) the impulse flashover voltage of the insulation, and (2) the minimum current required to raise the line to flashover voltage on a positive impulse of the 1.5 x 40 microsecond wave shape, this wave being about the equivalent of the lowest lightning surge that will cause flashover in service. These lines have no overhead ground wires. The current values in this table are qualified somewhat by the facts that the lightning severity was not the same for all lines and that the tendency of a power arc to follow surge flashover varies with the type of insulation and with the power voltage.

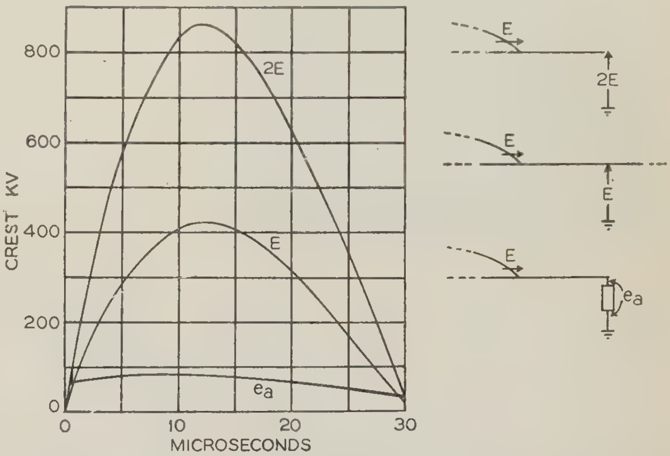

Fig. 3. Line surge equivalent to impulse test in figure 2. The test current determines the shape of the equivalent voltage surge as given in figure 1 (equation 3)

Taken with these reservations, however, the data in table II give an indication of the probable frequency of lightning disturbances involving impulse currents of 5,000 amperes or more. As they stand, these data indicate that exposed overhead transmission lines may be subjected to disturbances of major severity from 25 to 50 times per hundred miles of line per year, which is equivalent to one disturbance for every 20,000 to 10,000 feet of line per year, respectively. From these considerations of the possibilities involved in direct strokes of lightning, it appears that the proposed A.I.E.E. impulse test of 1,500 amperes is not representative of this service condition. The 16,000 ampere test illustrated in figure 4 is more nearly representative, and it appears that on very highly insulated lines short traveling waves may occur with currents up to 25,000 amperes.[20]

Table II—Flashover Records and Impulse Flashover Characteristics of Some Typical Overhead Transmission Lines

Reference No.	System Kv	Miles	Years	Flashovers or Outages per 100 Miles per Year	Surge Insulation, Distance, Inches	Approximate Minimum Impulse Flashover, Kv	Minimum Surge, Amperes to Cause Flashover
9	110	Average		25	84	1,350	5,400
10	66	38	1	16	84	1,350	5,400
11	220	40	2	59	70	1,100	4,400
12	132	21	6	40	64	1,000	4,000
12	132	40	6	50	47	750	3,000
13	110	75	4	19	40	650	2,600
14	140	226	2	19	50	800	3,200
10	66	38	1	240	24	390	1,550
15	33	1,045	1	45	18	290	1,150
16	60–100	738	1	26	34	550	2,200
16	30–60	4,277	1	30	12–30	200–500	800–2,000
17	100	213	3	29	33	390	1,550
18	30–60	2,375	1	35	12–30	200–500	800–2,000

Direct Strokes on Distribution Circuits

Overhead lines operating at from 2.3 to 33 kv will have a range of from 100 to 500 kv crest in minimum

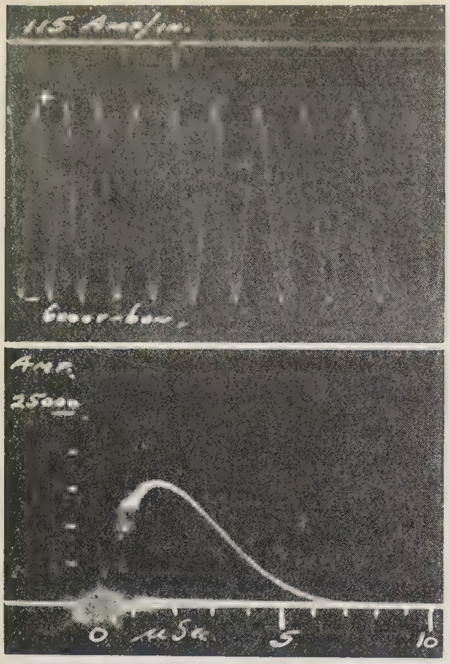

Fig. 4. Oscillograms of test on a 6,000 volt arrester connected to a 6,000 volt source while passing a 16,000 ampere test impulse

Top. Magnetic oscillogram showing power voltage across arrester and power follow current through arrester

Bottom. Cathode ray oscillogram of impulse

impulse flashover voltage from line to ground. A high current from a direct stroke or streamer terminating on such a line probably will be discharged to ground over 2 or more paths since the effect of the inductance of the paths or ground resistance, or both, is such that no one path will have a sufficiently low impedance to limit the line-to-ground voltage to the flashover value at adjacent points of low insulation. The flashover of additional paths to ground will limit the magnitude and duration of the current discharge through an arrester in the vicinity of a direct stroke to the line. Line-to-line flashover will distribute the total current among the arresters in a set.

General consideration of distribution line insulation leads to the conclusion that a set of 2,300 volt arresters may be expected to discharge half the current from streamers terminating on the line within 250 feet of them. Direct strokes or streamers to lines in exposed territory will occur more or less indiscriminately and the probability of a stroke to any single 500 foot section in a year is, as was derived previously in this paper, of the order of one in 20 to 40. Where lightning arresters or other protective devices are so arranged as to afford maximum protection to distribution transformers, i. e., 3 point protection, the arresters must discharge full impulse current. Past practice of using arresters separately grounded has resulted in transformer flashovers with high impulse currents, these flashovers in effect shunting current around the arresters.

Measurements on an urban distribution system have been reported recently by Halperin and McEachron[19] in which 24 current recorder years yielded only 1 current measurement of more than 300 amperes, this one current reaching a value of 1,500 amperes. It should be borne in mind that these data were obtained in sheltered urban territory where the probability of line disturbance is somewhat less than for a line through open country. Furthermore, records obtained on exposed transmission lines lead to the conclusion that a high current record need not necessarily have been expected during the period of time covered by these records.

H. W. Collins has published records[21] of surge currents measured in the common ground lead of 3 phase arrester installations on the Detroit Edison 24 kv system. Of the records obtained, about 4 per cent showed currents of more than 5,000 amperes; the highest was 34,000 amperes. About 1 in 12 arrester installations produced records of more than 5,000 amperes during one year.

Figure 4 shows a cathode ray oscillogram of a 16,000 ampere impulse passed through a 6,000 volt standard commercial arrester under laboratory conditions. The magnetic oscillogram of the same test records the power voltage across the arrester and the power follow current through the arrester. This 16,000 ampere impulse is of the order of magnitude of impulse currents that distribution arresters may be expected to encounter occasionally in operating service, but is by no means as severe as the *maximum* current that a protective device may be required to discharge in present day distribution service.

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Discussions

Of A.I.E.E. Papers—as Recommended for Publication by Technical Committees

ON this and the following 31 pages appear the discussion of a paper presented at the transmission and distribution session of the 1934 A.I.E.E. North Eastern District meeting, Worcester, Mass., May 16–18, and the discussions of papers presented at the 1934 A.I.E.E. Pacific Coast convention, Salt Lake City, Utah, September 3–7. All discussions on these papers received in complete and acceptable form at Institute headquarters, and subsequently reviewed and recommended for publication by A.I.E.E. technical committees, are included. Authors' closures, where they have been submitted, will be found at the end of the discussion on their respective papers.

Experimental Analysis of Double Unbalances

Discussion and author's closure of a paper by E. W. Kimbark presented for oral discussion at the transmission and distribution session of the North Eastern District meeting, Worcester, Mass., May 16, 1934, and published in this issue, p. 159–65.

H. W. Bibber (Ohio State University, Columbus): In commenting on Mr. Kimbark's paper, which I had the opportunity of reading in advance of the meeting, I should like to begin by commending him for the restraint he has shown in describing the general aspects of symmetrical component analysis. It seems as though everyone who digs into the subject deeply enough to master the principles involved feels moved to write an elementary exposition. I personally am no exception, and know the temptation to which he was subject.

Since the number of a-c calculating boards is so limited, it is fortunate that those having convenient access to them take the opportunity of trying out experimentally some of the methods that the rest of us may work out analytically. This brings out such interesting matters as the necessity for a phase converter if the "connection" method is to be employed, or the possible usefulness of the equivalent Π connection rather than the T which Miss Clarke developed in her 1931 A.I.E.E. paper on simultaneous faults. Thus the opportunity is provided for an extension of our knowledge such as Mr. Kimbark's paper represents.

From personal experience I know that the use of an induction motor running at or near its synchronous speed to serve as a phase converter has the disadvantages mentioned by Mr. Kimbark. I wonder if the possibility of using thyratron tubes with a suitable commutating circuit might not offer a chance for improvement, as it would be possible to secure much closer coupling because of the lower leakage reactance obtainable with transformers. Such a circuit would of course have to provide for energy storage, as the instantaneous power would be different in 2 circuits coupled so that the voltages are in the ratio 1:a or 1:a².

This paper indicates that further work by the author and others is in progress, which should make the a-c calculating board an even more versatile instrument. This is most encouraging and should lead to future developments of importance.

Edith Clarke (General Electric Co., Schenectady, N. Y.): Mr. Kimbark's paper (Fig. 8) shows a double unbalance consisting of a conductor shorted to ground and at the same time open, such as may occur when single pole switching is used or when a line is opened by fuses. When the circuit breakers at the 2 ends of the line do not open simultaneously there is a period, while the fault is still on the system, during which one end of the faulted conductor is open. If currents due to capacitance are neglected, and there are no circuits tapped off between the fault and the opening in the conductor, the opening may be assumed at the fault as in Fig. 8. System currents and voltages obtained under this assumption will be correct with the exception of the voltages along the conductors between the fault and the actual opening.

Mr. Kimbark has shown that this problem can be readily solved on the a-c calculating board by the "connection method." To solve it by the "equivalent circuit method," either mathematically or on the a-c calculating board, it is first necessary to determine the equivalent circuit to replace the double unbalance in the positive sequence system. This equivalent circuit is not given in the paper. Since an a-c calculating board is not always available and the problem is one of practical importance, the equivalent circuit will be given.

The 6 relations between the symmetrical components of currents and voltages at the points of unbalance, x and y of Fig. 8, are given by eqs 12 and 13 of the paper. The 4 equations pertaining to the negative and zero sequence currents and voltages at points x and y can be expressed in terms of C_0, D_0, S_0, C_2, D_2, and S_2, the impedances of the branches of the equivalent wyes which replace the zero and negative sequence systems between points x, y, and the zero potential planes for the system, subscripts

The Oklahoma City Oil Field

ONE of the items which will be of particular interest to those attending the A.I.E.E. South West District meeting, Oklahoma City, Okla., April 24–26, 1935, is the Oklahoma City oil field adjacent to the city. This general view of a portion of the oil field was taken in 1930 from a point just adjacent to the Oklahoma City business section, and shows a large number of wells in the process of drilling. The Oklahoma City field has 1,032 wells producing, with an average of one well for every 6 acres. This field has produced to date 240,000,000 barrels of oil; geologists report that an additional 125,000,000 barrels of oil will be produced within the next 5 years. Although the oil has flown almost entirely from its own natural gas pressure until within the last year, it is now necessary to use pumping on practically all wells. At the present time, the connected capacity in the field is 25,000 horsepower. This field has been the proving ground for developing the Reda pump.

0 and 2 indicating zero and negative sequence, respectively. Branch C is connected to point x, branch D to point y and branch S to the zero potential plane.

By eliminating negative and zero sequence currents and voltages from these 10 equations, 2 equations containing only the 2 positive sequence currents and the 2 positive sequence voltages at points x and y will remain. When these 2 equations are put in the form of eqs 16, it will be seen that $m = n$, and therefore the double unbalance can be replaced in the positive sequence system by an equivalent wye.

Let Z_x, Z_y, and Z_s be the branches of the equivalent wye between points x, y, and the zero potential plane for the positive sequence system, branch Z_x being connected at point x, the point of fault, branch Z_y at point y, the point of open circuit, and branch Z_s to the zero potential plane. Then

$$Z_x = -\frac{C_0 z_2 + C_2 z_0}{z_0 + z_2}$$

$$Z_y = \frac{C_0 z_2 + C_2 z_0}{z_0 + z_2} + \frac{z_0 z_2}{z_0 + z_2}$$

$$Z_s = -\frac{Z_x Z_y}{Z_x + Z_y} + Z_0 + Z_2$$

where

Z_0 and Z_2 are the zero and negative sequence impedances, respectively, viewed from the fault with no conductors open. z_0 and z_2 are the zero and negative sequence *series* impedances offered to zero and negative sequence *series* voltages, respectively, applied between points x and y with no faults on the system.

From the equivalent wyes with branches C_0, D_0, S_0, C_2, D_2, and S_2 representing the zero and negative sequence systems, the following relations may be obtained:

$$Z_0 = \frac{C_2 D_2}{C_0 + D_0} + S_0$$

$$Z_2 = \frac{C_2 D_2}{C_2 + D_2} + S_2$$

and

$$z_0 = C_0 + D_0$$

$$z_2 = C_2 + D_2$$

F. M. Starr (General Electric Co., Schenectady, N. Y.): Mr. Kimbark has made an interesting and valuable contribution to the existing literature on simultaneous faults and double unbalances in polyphase systems. His method of analysis on the a-c calculating board is novel and plausible. He has introduced the feature of coupling the phase-sequence networks through insulating transformers. As noted in the paper these transformers should be ideal ones, i. e., without resistance or reactance.

Coupling of this type may be introduced more accurately by using an equivalent linkage instead of an actual transformer. There are several such linkages but the most suitable one is shown in figure 1 of this discussion.

This linkage is composed of 6 simple impedance links which are already available on the calculating board. It may be given any resistance, reactance, and ratio characteristics which the particular system demands. In this case $L_1 = L_2 = M$, which corresponds to zero reactance and a ratio of unity. For derivation of this circuit, see "Equivalent Circuits—I," F. M. Starr. A.I.E.E. Trans., v. 51, June 1932, p. 287–98.

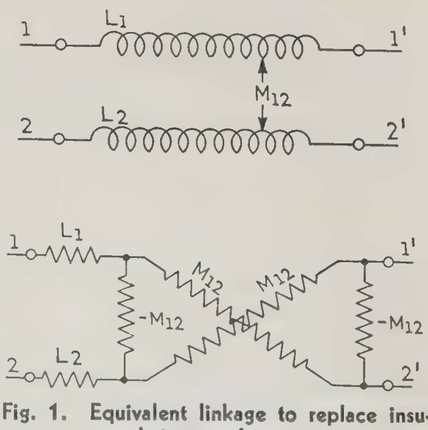

Fig. 1. Equivalent linkage to replace insulating transformer

E. W. Kimbark (Massachusetts Institute of Technology, Cambridge): Neither the ideal transformer nor the phase converter has been perfected. Therefore the suggestion of Mr. Starr, concerning the use of an equivalent impedance linkage in place of an actual transformer, and that of Mr. Bibber, concerning a phase converter using thyratron tubes, are most welcome.

An ideal insulating transformer of unity ratio has several uses in connection with the calculating board in addition to those suggested in this paper; for example, in representing the mutual impedance between parallel transmission lines not bused at either end,[1] and in setting up electrical analogues of structures.[2] Research to determine how the ideal coupling may best be attained, whether by a linkage of inductive and capacitive reactors or by a transformer, using in either case the best magnetic materials, would seem worthwhile. If neither method gives sufficient precision for desired application, various methods of compensation can be resorted to. Mallock[3] has devised an automatic method of supplying exciting current; another possibility is to supply the exciting power mechanically, and the reactive volt-amperes by condensers, as has been done for the phase converter. Similar means might be used to compensate for the leakage impedance.

Perhaps it should be pointed out that the linkage presented by Mr. Starr is not "ideal" unless the reactors can be built with no resistance. At the same time the reactance values should be very high to reduce the exciting current to a negligible quantity. The equivalence between the linkage and the transformer holds only at a single frequency; as the calculating board is operated at a constant frequency, this is satisfactory, provided that the circuit is not too sensitive to small frequency fluctuations.

My paper did not go into much detail on the equivalent-circuit method, as the principal contribution was believed to lie in the extension of the connection method. Miss Clarke's discussion therefore serves to amplify that part by deriving the equivalent T or wye circuit for one type of combined series and shunt unbalance. The derivation of equivalent circuits for simultaneous faults is given in her own paper (reference No. 3 in the paper). It will be observed that the resulting algebraic expressions are rather complicated. The use of the connection method dispenses with a large amount of algebraic and arithmetical work.

References

1. Discussion by W. A. Lewis of F. M. Starr's Equivalent Circuits, A.I.E.E. Trans., v. 51, June 1932, p. 323.

2. Structural Analysis by Electric Circuit Analogies, V. Bush. *Jour. Franklin Inst.*, v. 217, March 1934, p. 289.

3. An Electrical Calculating Machine, R. R. M. Mallock. Royal Soc. *Proc.*, series A, v. 140, May 3, 1933, p. 457.

The Insulator String

Discussion and author's closure of a paper by R. W. Sorensen published in the August 1934 issue, pages 1221–4, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): Sorensen's time load tests on suspension insulators supplement similar tests that were started some years ago and which are being continued by various insulator manufacturers. In general, the log of his tests checks similar results on tests with which I have been associated. According to the figures, the longest duration of any of the tests so far recorded was 140 days. No doubt the test will be continued as it is of interest to compare performance over a period of some years.

From the illustration in figure 1 of the paper it appears that the test set-up is in a laboratory. Such location and performance over a short period as reported offers a good comparison of the relative ability of the insulator designs to distribute sustained load stress. The dielectric failure of the insulator may be assumed to occur when the critical fatigue limit is reached. This limit is a product of maximum stress in the porcelain and time. No mention is made of the insulator being subjected to temperature changes. Differential expansion is an important factor in determining the resultant stress of load and thermal changes. The addition of thermal changes to the load test would provide a more complete comparison of performance. The performance of such combined tests is reviewed in my paper in Electrical Engineering, June 1934, pages 867–70.

The data compare the respective performance of the different insulators on the several loads. Supplementing the authors first conclusion the evaluation of each individual design can be determined by comparing its time load performance with its average A.I.E.E. combined mechanical and electrical strength and its ultimate strength. As an example, I have observed that a commercial suspension insulator with an average A.I.E.E. combined mechanical and electrical strength of 22,000 pounds suffered failures

in 60 per cent of the units in one week at a load of 10,000 pounds. Another design with an A.I.E.E. strength of 15,000 pounds has shown no failures in 2 years at a load of 11,500 pounds. Obviously, the latter insulator is superior in design.

In his second conclusion the author attributes the improvements in the last 15 years to the first half of this period. This may apply to some extent to manufacturing processes but the features of design that are responsible for the marked improvement in mechanical performance were developed, as indicated by literature of the Institute, during the latter part of this period. The only glass suspension insulator developed commercially during this period has a poor ratio of time load to quick time test values.

Conclusions 1 and 4 are in accordance with good engineering practice.

W. A. Hillebrand (University of California, Berkeley): The tests reported by Sorensen are valuable because they contribute to our knowledge of insulator performance under a known set of conditions, and information so difficult and expensive to obtain is doubly welcome. The careful and thorough manner in which the tests have been made leads to the hope that they will contribute to our understanding of the insulator problem.

However, it must be recognized that 90 per cent of suspension insulators are used where they can never during their lifetime be subjected to a load greater than 5,000 pounds, even on the most heavily loaded line. The standard 10 inch disk today is designed for 15,000 pounds mechanical and electrical strength, with a strong tendency to appraise competitive designs by their ability to pass high time-loading tests.

The justification for this course has been clearly stated by one engineer as follows: "Although it is not proposed to use insulators at higher working loads than formerly, nevertheless it is felt that the ability to support sustained, high loads without failure is proof of low specific stresses in the dielectric at the usual working loads and should result in a longer lived insulator." Such a line of reasoning stresses the loading test, places a premium upon the maximum values, and forces designers to use thicker and thicker parts because the elastic limit in the metal obviously may not be exceeded.

The use of heavier metal parts imposes higher thermal stresses upon the 90 per cent of insulators in suspension position, and suspension insulators fail. Therefore, in the writer's opinion, the results of time loading tests are useful, principally in connection with thermal tests in estimating the relative merits of different designs.

Referring now to specific parts of the paper, the values of figure 10 are presumably dry flashover at 50 cycles. Is this not so? Were corresponding data obtained with impulse voltages and at power frequency with insulators wet?

In the last paragraph on page 1224 it is stated that careful maintenance should permit the occurrence of not over 2 bad insulator units per string. A requirement as onerous as this would impose an unreasonable burden of inspection and testing and is probably impossible of fulfillment. The distribution of depreciated units among the various strings will, in general, be of a random nature according to the law of probability. This means that with a 13 unit string and 5 per cent of the total number of insulators bad, there would be a total of 650 bad insulators per 1,000 strings with a probable distribution as follows:

351 strings with 1 unit bad
110 strings with 2 units bad
21 strings with 3 units bad
4 strings with 4 units bad

If lightning is the principal hazard, the probability of a tower being struck which supports one of the strings with 3 or 4 bad is slight. However, if the hazard is due to a combination of the operating voltage, dirt, and moisture, a single string with more than the minimum permissible number of bad units is likely to fail.

G. M. Whistler (Westinghouse Elec. and Mfg. Co., Emeryville, Calif.): A review of Barrow's comments suggests certain amplifications within the $7^1/_2$ year period referred to by Sorensen, during which time little development has been made according to his claim. It should be emphasized that for the first year or 2 of this period it was very difficult for the majority of the insulator companies to meet successfully with any degree of consistency a 6,000 pound time load test for even 72 hours.

At the present time, as indicated by Barrow's and Hawley's papers, such tests can be met with a greater degree of success at loads increased from 75 to 100 per cent. This indicates very definite improvement in suspension insulator designs, particularly when it is considered that the head and cap dimensions for the present day 15,000 pound insulator are considerably smaller than in the former 9,000 or 11,000 pound insulator. Using dimensions similar to these former insulators, it is possible today by reason of improved design to meet strengths essentially in the high strength of 25,000 pound class. These improvements, as indicated by the papers referred to, were accomplished by design details which utilize the vastly greater compression strength of porcelain and subject the insulator to rise of tension and shear components.

R. W. Sorensen (California Institute of Technology, Pasadena): Barrow's deduction as to the tests being conducted in a laboratory and that, therefore, the insulators on which the tests were made were free from differential expansion due to temperature changes, is correct. In fact, the particular laboratory in which the tests were made is one that is very free from any sudden changes in temperature, humidity, or barometric pressure, and is, because of the absence of these changes, all the better suited as a laboratory for such tests as those under discussion.

We have considered similar tests made with temperature changes and continuously applied voltage, but so far for the purpose we had in mind have thought them of insufficient value to warrant the trouble and expense involved in their making. On the other hand, the insulators, as was mentioned in the paper, have not been wholly without the effect of stress changes because each unit as it failed was replaced by a new one, an operation which required the unloading of the string and a reloading thereof. Our experience on this test showed quite clearly that these changes in loading were a factor in shortening the life of many units as compared to what the life might have been with no fluctuations in load.

As I examine the tests I have reported, I am not at all inclined to agree with Barrow's inference that our tests show that "the only glass insulator developed commercially during this period has a poor ratio of time load to quick time test values," unless he includes in his statement that most of the porcelain insulators act the same way; because, as a matter of fact, in the paper by intention I have very carefully avoided any notation which would show the type or make of insulator to which the data given applies. But, he has brought up the subject, I think it only fair to state that the glass insulators we tested had a life expressed in pound days of load well above the average of the insulators covered by the report made in my paper.

I do not think any reply is needed for the comments of Hillebrand and Whistler, other than to say that none of the discussion given has changed my opinion that 13 units per string will be ample for most of the 230 kv transmission lines which will be used by the Metropolitan Water District to supply power from Boulder Dam to its pumping stations.

Field Tests on Conductor Vibration

Discussion of a paper by E. M. Wright and J. Mini, Jr., published in the July 1934 issue, pages 1123–7, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

A. E. Davison (Hydro-Electric Power Commission of Ontario, Toronto, Can.): The conclusions drawn and recorded in this paper are the result of experimental work and should receive more than ordinary attention because they appear to cut across a considerable number of thought and idea paths. These conclusions may even encounter some prejudice. For instance, it is a little difficult to reconcile the conclusion that "for the particular type of conductor and dampers tested, one damper installed on the conductor approximately 4.5 feet (1.37 meters) from the suspension clamp at each end of the same span will sufficiently limit vibration under all conditions and is better from a damping standpoint than an additional number," with the record found in *Electrical West*, April 1934, page 34, wherein photographs record the installing of absorbers 2 or more at a time under comparatively strenuous and difficult conditions. It may be that quite a different type of conductor damper is being recorded by the photographs referred to in the magazine, or it may be that when the work illustrated is finished only one absorber will be used at each end of the span, thereby conforming to that more economical practice pointed out in the paper.

Prejudice may also be encountered because of the industry's having introduced,

during several years past, a considerable number of trunnioned clamps, first used in Germany as far back as 1897 or thereabouts. For instance, conclusion number 4 states that "the tendency to either retard or aid the transmission of vibration waves from one span to the adjacent ones" is not noticeably different when using trunnion or nontrunnion types of clamps. It will be inferred from this conclusion that fatigue is similarly not affected. Alternately, a recent investigator in Europe (H. Maass, Elektrotechnik und Maschinenbau, Jan. 14, 1934) seems to have satisfied himself that there is an improvement in the life of the equipment when using trunnioned clamps for he says, according to translations, that cables suspended in the older types of clamps were ruptured after 3 million vibrations, artificially applied, whereas new types of clamps investigated similarly but using lighter material and rotating about an axis at right angles to the cable showed considerable improvement.

Certain questions arise regarding the interpretation of the data secured. For instance, is it good practice to assume that the undamped conductor can be taken as a basis for observation of the other 2 conductors? We think that the recorders as indicated in figure 1 of the paper may of themselves introduce a considerable suppression, or may break up certain of the wave systems or trains which are being generated in both the damped and undamped cables. Are we reasonably sure that this damping, if any, by the instruments themselves is having a similar or equal effect in the vibrations which are being investigated, first in undamped and second in damped spans?

Can it be correctly inferred from figure 4 of the paper, where 3 dampers and 2 dampers per span at one end are indicated, that 2 dampers are actually better than one in suppressing vibration? Some readers might not so interpret the charts.

Is it correct to infer from figure 5 that the distance from the tower at which recorders are set has some bearing on the resulting records? It apparently is not clear in the paper whether the damper experimented with was especially designed for the particular type of conductor or the standard commercial article picked at random and used on the particular cable.

G. W. Stickley (Aluminum Company of America, Massena, N. Y.) and **H. L. Anderson:** Certain tests described by the authors, studying damping effects of different numbers and spacings of Stockbridge dampers, are similar to some made at several field laboratories of the Aluminum Company of America, a preliminary report of which was made several years ago. (Vibration of Overhead Transmission Lines, R. A. Monroe and R. L. Templin. Electrical Engineering, July 1932, pages 482–7, and August 1932, pages 562–8.) It is of interest to note that in such cases the results in general are in close agreement. In this connection there are several comments which can be made.

In their conclusions, the authors state that although the conclusions "apply only to the type of conductor, the particular location, span, and tension used, it is quite probable that the same general conditions would be found in other conductors, regardless of size, tension, and span." Referring to the first conclusion, this should not be interpreted as meaning that for all sizes of conductors the best location for the dampers is 4.5 feet from the suspension clamp, for this factor, like damper weight, naturally varies with cable diameter, as shown in figures 1 and 2 of this discussion.

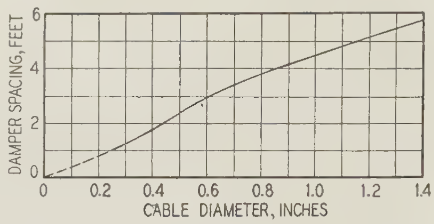

Fig. 1. Stockbridge damper spacing

Spacing of dampers is from center of suspension clamp, edge of insulator groove, or mouth of dead end

Similarly, referring to the second conclusion, the most prevalent frequencies will vary inversely with conductor diameter, and also may be different in different locations. At Massena, N. Y., 795,000 circular mil aluminum cable steel reinforced has been observed to vibrate with frequencies of from 4 to 40 cycles per second, the most prevalent being from 10 to 30 cycles per second.

The first conclusion also states that "one damper... at each end of the same span... is better from a damping standpoint than an additional number." With dampers of the design which we have found most adequate when used singly at each end of average length spans, our observations have shown no diminution in damping effect from the use of additional dampers. The amount of work to be done by dampers naturally increases with span length, and it would seem logical to vary either the damper weight, or the number of dampers, with the span length. The former is undesirable because, if the ratio of damper weight to unit weight

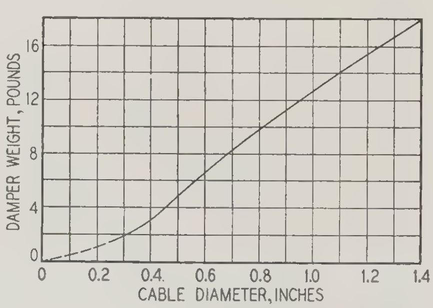

Fig. 2. Stockbridge damper weights

of the conductor becomes too great, a reflection point may be formed at the damper, with resulting decrease in damping efficiency. For this reason, and also for simplicity, our work has led to the development of one size of damper for each conductor diameter and the use of more than one damper at each end of the span where the span length is sufficiently great to require it. This led to observations for determining the limiting span length for the use of one damper at each end. For 795,000 circular mil aluminum cable steel reinforced we have chosen this limit conservatively at 1,000 feet. The limiting span length for 2 dampers at each end has not yet been definitely determined, but is at least 2,000 feet.

The results of the tests of the effect of trunnion versus nontrunnion clamps confirm our ideas regarding the relative merits of these 2 general types, our ideas formerly having been based partly on observations in endurance tests made on 120 foot spans in an indoor laboratory with mechanically vibrated test samples.

Figures 1 and 2 of this discussion are based on tests made at 3 locations, including 870 foot and 1,060 foot spans in an actual transmission line in New Jersey, and experimental spans from 400 to 1,225 feet long in Texas and New York. These tests to date cover a period of more than 30 months, and include approximately 8,500 24-hour vibration records from 7 different sizes of conductors from 0.25 to 1.40 inches in diameter. In addition, certain of the data shown have been confirmed in records from spans in actual transmission lines in other parts of the United States and in foreign countries.

Insulator Surface and Radio Effects

Discussion of a paper by W. A. Hillebrand and C. J. Miller, Jr., published in the August 1934 issue, pages 1213–20, and presented for oral discussion at the transmission session of the Pacific Coast convention, Salt Lake City, Utah, September 6, 1934.

W. A. Kates (Corning Glass Works, Corning, N. Y.): I note that the authors conclude from their tests with needle gaps in foggy atmosphere that the dielectric strength of air is a maximum under fog conditions, and I wonder whether this was also corroborated by sphere gap tests. I would expect sphere gap sparkover to be increased if the effect noted was an increase in strength of the air itself.

I would like to ask the authors if, in their experiments with liquid electrodes and the arrangement of figure 1, the effect of the glass adjacent to the liquid electrodes was the same as for the metal electrodes. Were glass strips fastened to the brass electrodes when the upper curve of figure 2 was taken? Also, would the lower curve of figure 2 be greatly changed if the glass surface were continuous across the space between the 2 liquid electrodes, as it would be, of course, on the top skirt of a pin type insulator supporting 2 charged drops?

Figure 3 of the paper shows a simplified representation of the circuit made up of the different parts of an insulator. It seems to the writer, however, that this circuit is not quite complete and that the inclusion of the additional elements in the diagram leads to conclusions differing from those of the author. Successive portions of the dielectric of an insulator are quite conveniently represented by the capacitances C_1, C_2, and C_3. Also, air gaps are in parallel with all of the capacitances, and each

capacitance is shunted by the surface resistance of the insulator. Let us for purposes of discussion represent these by R_1, R_2, and R_3. Assume further that C_1 and R_1 represent the capacitance and surface resistance, respectively, between the tie wire and a portion of the surface 1 centimeter away, "air line" distance. The sum of R_2 and R_3 will then be much greater than R_1. This is true so long as a reasonably uniform surface resistance per square inch obtains. If, now, R_1, R_2, and R_3 are all decreased, there should be less tendency to break down the gap G because there will be a lower voltage between the tie wire and the point on the adjacent insulator surface. This is especially true in the case of the common pin type insulator where R_2 and R_3 probably do not decrease in value in direct proportion to the decrease of R_1.

The foregoing predicts less corona on a pin type insulator, for example, when the surface adjacent to the tie wire is conducting. This is confirmed by our experience in the design of corona-free insulators. The elimination of corona at the tie and line wires presents very little difficulty; it is the termination of the surface coating which is the problem, as this coating must be terminated under such conditions of electrostatic field as result in no edge discharge.

Our experience as outlined confirms the authors' discussion concerning figure 7. I would interpret it as at variance with their conclusions from figure 3, however.

The experimental apparatus of figure 4 and the use of wash water from insulators as a surface coating is quite ingenious. However, there is one important difference between conditions in this apparatus and those of a pin type insulator. In the test apparatus, the electrostatic field at the dielectric surface is generally parallel to this surface, even though there is a bottom plate of conducting material. To the contrary, in a pin type insulator, the field is generally perpendicular to the top skirt. This difference is fundamental and would result in different edge effects of the dielectric adjacent to the electrodes and hence different relative test results as well as absolute ones.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): The authors' investigation and determination of the surface contamination on insulators exposed to salt, fog, and dust, and their exposition on wet arcover and initiation of an arc on an insulator, are of interest. The results of the radio interference measurements in table III indicate that such coating on insulators becomes conducting under conditions of high relative humidity or fog to a degree sufficient to cause disturbance. Perhaps the statement at the end of the section on radio influence "that a pin type insulator should exhibit corona at the tie wire at a much lower voltage when its surface is coated with a conducting film than when it is not coated" should be qualified. A conducting coating in contact with the conductor or tie wire reduces the potential gradient over those areas. This is a form of treatment that improves the radio interference characteristics of a pin type insulator as reviewed in Gilchrest's paper, Electrical Engineering, June 1934, pages 899–903.

Referring to the authors' mention of the diminishing intensity of interference at distances from the transmission line, and the absence of any interference in receiving sets in nearby residences, it is of interest to note that, if the receiving set is beyond the field of influence of the line itself, in some cases disturbance may be conveyed to the receiver on the service taps by carrier current effect.

As the authors suggest, one remedy for the conditions they investigated is to keep the insulators clean of contamination which is both expensive and difficult. It is doubtful if the low capacity type of insulator to which they refer would offer any improvement as the causes of interference are surface conditions which would develop with any type of design.

F. W. Maxstadt (California Institute of Technology, Pasadena): It is stated in the fourth paragraph of the paper and again under the heading "Initiation of an Arc" that between 30 and 60 milliamperes are required for a preliminary arc "to be maintained until the gap between conductor and ground is bridged." Since this is an extremely important observation it would be helpful to know whether the value was measured by means of an ammeter in series with the insulator just prior to arcover or calculated from measured surface resistance or obtained in some other way.

If such a value applies over a wide range of insulator shapes and sizes and is determinable without high voltage equipment but instead may be calculated from megger readings, a new means of predicting impending insulator trouble is available.

In order to check this observation, I have prepared glass rods 2 inches in length but of diameters varying from $^1/_4$ to 2 inches. One after another these rods were placed between parallel plates and sprayed with a mixture of magnesium chloride and table salt (about 150 milligrams of each dissolved in 75 cubic centimeters of distilled water), tested for wet and dry resistance, and flashed over. In each case the flashover voltage was about 8,500 wet and 21,000 dry (effective value). Strangely enough, the wet surface d-c resistance was about 300,000 ohms measured at 550 volts for each rod in spite of the ratio of 8 to 1 in extreme diameters. Taking into account the series protective resistance of 50,000 ohms, an initial current of about 25 milliamperes should flow.

When, however, a 50 milliampere meter was placed in series with the test sample and the voltage raised to near the flashover value, very erratic currents were observed, some swinging the meter off scale and some making it swing to 30 or 40 milliamperes. Even these flashes did not cause complete arcover and their peak currents must have been well over 60 millamperes in order to swing the meter needle up so high on impulses of very short duration. In these tests the only difference between the behavior of the 2 inch and the $^1/_4$ inch diameter rods was in the rapidity with which the latter dried out as compared to the larger rod. Only a matter of 5 or 10 seconds was required to dry the coating completely and reduce the leakage current to a minute value. Since a spark probably forms in only one narrow channel at a time, the diameter of the test piece should have nothing to do with the initial current required to cause complete arcover. That initial current, however, is well over 60 milliamperes and can probably be measured only with the cathode ray oscillograph. Insulator surface resistance as measured with a few hundred or even 1,000 volts has no direct relation to the current in question since the gaps that afford spark paths are high resistance paths in the resistance test and are short-circuited by sparks in the arcover condition.

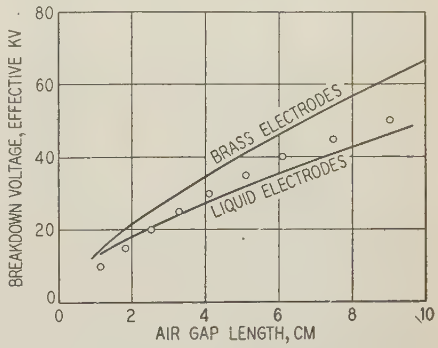

Fig. 3. Curves of breakdown voltages of brass and liquid electrodes

o = Needle gap

When these samples were wet the initial glow, which formed on the surface as the voltage was raised, occurred at about 1,200 volts maximum or 600 volts per inch. It was barely visible at a distance of 2 feet in a very dark room and covered only a small fraction of the insulation surface. The value of 400 volts per inch given in the paper probably depends more upon size of insulator and total voltage than upon any calculated gradient.

In connection with the laboratory test specimen the statement is made that "the purpose of the annular ring was to provide a definite path uniform in all directions for leakage currents." It must not be supposed that the current density or voltage gradient will be in any sense uniform since a radial field is decidedly nonuniform. It would have been interesting to test in the laboratory some of the insulators actually used on the power line. The voltage of initial radio influence in terms of humidity and other tests such as those made on the artificial specimen might have yielded valuable information.

On page 1215, referring to the discrepancy in capacitance between the laboratory specimen and the commercial pin insulator, the authors state that the former was about twice that of the latter "so that corona for clean surfaces should occur at a lower voltage than for an insulator." I see no reason for a relation between capacitance of an insulator and its initial corona voltage unless the electrode area enters into the relation.

In table I the surface resistance as measured between electrodes in the laboratory test specimen when "clean" may have no meaning because of the uncertain area of contact between an approximately flat piece of brass and an approximately less flat piece of glass. When contaminated with wet conducting material the value is no doubt reliable.

In table II the last 2 lines, for clean glass surface, show diminishing radio effect for increasing relative humidity, whereas for contaminated surfaces the trend is in the opposite direction. This is not explained. Also it would have been considerably more convincing to have figure 7 actually completed to show the falling off of radio effect above 90 per cent humidity as predicted.

I offer figure 3 of this discussion with the addition of values of the average needle gap voltages as given by Peek in "Dielectric Phenomena in High Voltage Engineering," 1929 edition page 117. This comparison indicates that liquid electrodes with no intervening medium but air act like needle points. To be sure, for gaps below about 3 centimeters they have a slightly higher breakdown strength than the needle gap and for gaps above that length the liquid seems to be scattered into the gap by the intense electric field at the electrodes, so that the effective gap is reduced in length and hence in breakdown voltage.

When, however, as is often the case in the practical insulator, there is a solid surface extending between liquid electrodes, the voltages indicated in figure 2 should be reduced by 50 per cent or more. Figure 3 of the paper "Insulator Arcover in Air," F. W. Maxstadt, Electrical Engineering, July 1934, page 1062, will show the effect of the presence of insulation surfaces between electrodes when the field is uniform. Approximately the same ratio may be expected for non-uniform fields.

In table III it would be interesting to know whether the 100 per cent humidity points are for fog, dew, or rain.

The authors suggest that the effect of sand and clay particles which stick to an insulator surface is to provide points for electrical discharge to take place. Experiments by Schwaiger (See "Theory of Dielectrics," A. Schwaiger, translation by R. W. Sorensen, John Wiley, 1930) on the arcover voltages of many substances in uniform fields indicate that roughness of an insulator surface has no effect upon the arcover voltage. Since in the commercial insulator no attempt is made to polish the electrodes or smooth down minute points, it would seem unlikely that particles of sand and clay on either insulator or electrodes would have an influence on its electrical behavior.

Hillebrand and Miller have brought out some very important observations. If radio effects cease at a distance of no more than 300 feet from a disturbing power line the great bulk of radio listeners have nothing to fear from such sources. Perhaps slow voltage branch lines can be completely isolated so as to transmit none of the radiations.

Since commercial insulators as used on power lines seem to be comparatively free from radio influence when dry or when clean and moist, according to the tests reported, and are still satisfactory when dirty and moist but operated at lower voltage, there are 2 not unreasonable remedies for power line radio influence. The first is to keep the insulators clean. The second is to provide additional insulation so as to reduce the voltage per unit to the range of quiet operation.

Radio listeners in metropolitan areas have nearby powerful broadcast stations to which to listen. These same areas are comparatively free from radio influences because of the pressure brought to bear upon the offenders. The combination is favorable to the listener. Conversely, the farther one goes from a metropolitan area the less likely he is to get satisfactory radio reception. There are 2 important factors working against him. First he must use a much more sensitive receiver to reach out for his favorite programs, because of greater distance to the broadcast station. Second, he is likely to have a great deal more local radio influence because of indifferent maintenance of the electrical transmission and distribution equipment in his neighborhood. If the disturbances from a high voltage transmission line extend only 300 feet, it should be commercially feasible to limit them to that area and prevent their extension over other circuits which can be made quiet in themselves.

Wide-Band Open-Wire Program System

H. S. Hamilton, April 1934 issue, pages 550–62.

Line Filter for Program System

A. W. Clement, April 1934 issue, pages 562–6.

Discussion of papers presented for oral discussion at the communication session of the Pacific Coast convention, Salt Lake City, Utah, September 3, 1934.

D. I. Cone (The Pacific Tel. and Tel. Co., San Francisco, Calif.): In assessing the value of the work reported by Hamilton and Clement it is important to bear in mind the greatly extended width of the transmission band of frequencies necessary for program transmission as compared with that for commercial messages. The field tryout and application of the wide band open wire program system involve the organization of apparatus, installation, and testing procedure over thousands of miles of line and in dozens of offices in such a manner as not to interfere with the commercial service being continuously rendered over the same pole lines and apparatus and even over the very wire circuits used for the experiments with the new facilities.

That the experiments were carried out and the new facilities placed in readiness for service with practically no interference of any kind with commercial working schedules is a tribute to the work of the authors and of their many associates in the numerous offices and companies whose plant and operations were involved.

The result is a system that meets highly exacting requirements of fidelity, that requires minimum effort to maintain it in satisfactory operating adjustment, and that takes its place in the open wire lines surrounded by numerous other communication channels over the distances necessary in transcontinental program service.

Joint Use of Poles With 6,900 Volt Lines

Discussion of a paper by W. R. Bullard and D. H. Keyes published in the December 1933 issue, pages 890–8, and presented for oral discussion at the management and protective devices session of the Pacific Coast convention, Salt Lake City, Utah, September 4, 1934.

W. G. Rubel (Mountain States Tel. and Tel. Co.): The "Principles and Practices for the Joint Use of Wood Poles by Supply and Communication Companies" were formulated by the joint general committee of the National Electric Light Association and the Bell System in 1926. Since that time a large amount of research work has been done with a view to increasing the safety in situations where joint use at the higher distribution voltages appears to be the best over-all engineering solution. These studies have included investigations of a number of cases of actual contact between supply wires and telephone plant. The information now available shows conclusively that under unfavorable conditions the results of such contacts may be serious. However, coördinative measures have been developed such that under favorable conditions their application will reduce the hazards involved in joint use at these higher voltages so that they are comparable with those involved in many existing situations of joint use with the ordinary distribution voltages. This paper describes a situation involving favorable conditions. Prompt deënergization of the power system following a contact is one of the most important considerations. Other favorable conditions include limited fault current, the presence of telephone cable or paired wire rather than open wire, and low resistance protector grounds at telephone subscribers' stations.

Although excellent progress has been made in the study of the problem of higher voltage joint use, no general solution has been found and it is therefore necessary to adhere to the practice of entering into such joint use only in those cases where specific study shows it to be the best over-all engineering solution. Field engineers of the operating companies of the Bell System, appreciating the desirability and advantages of joint use distribution, would welcome a solution of the problem which would permit a more general application of joint use than has heretofore been thought feasible in situations involving voltages of over 5 kv. With the progress already made and the coöperative studies now under way by the joint committee, there is every indication that such a solution will shortly be reached.

While the construction of separate nonconflicting power and telephone lines to avoid joint use with the higher distribution voltages will in many cases reduce the probability of contacts, this is not always true where numerous drop and service wire crossings result. Furthermore, the construction of separate lines in built-up areas is often not satisfactory from the public's standpoint and the economies and other advantages generally associated with joint use are, of course, sacrificed by such construction. In view of these facts, any proposal of a

power company to use circuits of over 5 kv for house-to-house primary distribution in a particular urban area directly affects the telephone company operating in that locality, whether or not the power and telephone circuits are to be carried on joint poles. Any decision as to the use of such distribution voltages in built-up communities should, therefore, be based not only on a joint consideration of power system economies and advantages, but also upon a joint consideration of changes in the degree of safety to telephone plant and equipment which may be involved.

In rural areas where both power and telephone distribution is relatively much less dense, it is often practicable and more economical to maintain separate pole lines on opposite sides of the road. Where the telephone circuits are made up of open wire, and water pipe grounds are not available at subscribers' premises, both the hazard and induction problems involved are much more difficult than in urban areas where the telephone circuits are carried in cable and there are water pipe grounds at subscribers' stations. In rural areas, however, important economies could sometimes be effected through joint use if the hazards and induction difficulties could be taken care of at a reasonable cost, and it is therefore important that each situation of this kind where joint use is proposed be carefully studied.

The degree of hazard in any situation involving possible contact between power wires and telephone plant cannot be measured solely by the voltage of the power circuit. A number of factors must be taken into account, among the more important of which are:

1. The maximum voltage to ground which can reach the subscribers' stations or the central office as the result of a contact.
2. The maximum current that can flow from the point of contact to ground *via* the telephone plant.
3. Whether cable or open wire telephone circuits are involved.
4. The length of time that a power wire may remain energized and in contact with the telephone plant.
5. The resistance of telephone station protector grounds, cable sheath grounds, and central office grounds.
6. The probable frequency with which contacts may be expected to occur.

Even with the greater strength of construction, better clearances, and higher insulation employed with the higher voltages, accidental breaks are liable to occur in both the telephone and power conductors which may result in direct contact between the 2 classes of circuits. Safety is a relative matter, and there is no known method of constructing pole lines carrying both open wire power circuits and telephone plant that may be said to be entirely free of hazard. Therefore, the selection of coordinative measures to be applied in any given case of joint use is largely a matter of judgment, and the ones selected will normally be those whose costs are not out of proportion to their benefits from a safety standpoint.

P. P. Ashworth (Utah Power and Light Co.): This paper is of utmost importance and value because it indicates that a step has been made in the right direction; that is, toward the elimination of an arbitrary voltage limitation for joint use in favor of procedures based upon sound economic and engineering analyses of the specific situation involved. I commend this method of approach to the problem of joint use.

It was no surprise to me that the 6,900 volt system was proved more economical than the 2,300 volt. In fact, to those of us in the West, who are accustomed to the use of higher distribution voltages, the economic answer would have been quite obvious from the beginning.

I am not sure that I would have stopped at 6,900 volts delta, unless some unusual obstacles prevented, but probably would have gone to 11,500 volts wye so as to get the outstanding advantages of the wye system over the delta. An 11,500 volt wye system, with the neutral wire bonded to the telephone cable messenger and grounded at frequent intervals, would, in my opinion, be a safer and better scheme than the 6,900 volt delta system selected. With the wye system the special grounding bank would have been unnecessary.

In our approach to the joint use problem I believe we should, at the outset, separate the cases into 2 distinct classes, and build up construction specifications with the particular class in mind. One class would involve power and open telephone circuits, and the other power wires with lead sheath telephone cables. The conditions and hazards are quite different in the 2 classes of joint use, and the specifications should take account of this fact. Personally, I cannot see that, with proper relaying of the power circuit and protective grounding, the voltage, or even the grade of construction, has much to do with the hazards to a sheathed telephone cable on jointly used poles, whereas these factors are all-important when open wire circuits are involved.

In every case the design features should be clearly set forth at the outset, as was done by the authors in the study described in the paper.

It may seem, at first thought, that a major application of higher voltage joint use will be on rural lines. However, modern rural line practice dictates the use of long spans of 250 feet and more. The extra costs, etc., of providing and maintaining high-grade construction for joint use on such lines will, in most cases, justify building separate pole lines.

R. F. Penman (Electric Bond and Share Co., New York, N. Y.): Joint construction at the lower distribution voltages has been and now is so well established that we cannot question the continuation of this practice or the benefits to both the power and communication companies using it. Many separate power and communication leads now in the same alleys, streets, or highways will be combined on joint poles when their condition warrants reconstruction and simplification.

Many of the power utilities have found it an economic necessity also to establish and use a higher distribution voltage such as 6.9 kv, 11 kv, 13.8 kv, or higher. Joint construction at these voltages would appear to offer comparable advantages to those already realized with joint construction at the lower distribution voltages if the personal and property hazard be not increased.

Many companies have already entered into extensive joint use with their higher voltage distribution lines. Replies to a recent questionnaire distributed by the Edison Electric Institute showed that 54 per cent of the companies answering reported that they had some joint use at voltages above 5 kv, varying in extent from a few poles to over 300 miles, and including a total of over 1,000 separate cases.

Even though this relatively extensive joint use at the higher distribution voltages has been entered into we all appreciate that the problem is far from solved as both utilities must coördinate their facilities not only for the maximum economy but with careful attention to the reduction in hazards to customers operating personnel, and the utility plants.

Studies of the mutual problems of the power and communication utilities have been undertaken coöperatively by the E.E.I.-Bell System joint subcommittee on development and research. The representatives of these 2 pole-using utilities on this subcommittee have made notable progress in determining the basic factors covering the proper methods to employ in the proper coördination of the 2 plants. It appears to me that this is the only practical method of attack in dealing with mutual problems of this nature.

One of the questions raised was whether there was economic justification for the power companies to have or to increase their distribution voltages above 5 kv. The Staten Island situation was selected as a specific case for study and the paper by Bullard and Keyes has given the results of this study very clearly.

It is indeed interesting to find that the change from 2,300 to 6,900 volts reduces the distribution investment by $571,000 and reduces the losses by 24,000,000 kilowatt hours over a period of 20 years. The study clearly justifies the conclusion drawn, namely, "The adoption of the higher voltage in the power system appears, therefore, to provide the best engineering solution in this case and joint use of facilities apparently may be entered into in all instances in Staten Island where the 2 services should preferably be placed on the same poles."

The decision in favor of joint construction in the Staten Island area not only recognizes the advantages from an economic standpoint but also clearly illustrates the splendid attitude of coöperation which now exists between the power and communication engineers.

Some may be inclined to criticize this paper on the ground that it covers almost an ideal case for higher voltage joint use as the average spans are short, grounding conditions are good, and the telephone circuits are largely in cable. However, this thorough treatment of a relatively simple specific case appears to me to be the logical first step in treating a very complex and involved general problem for which we hope and expect a satisfactory solution will be found through continued coöperative effort and study.

A similar study has been made of the joint use situation at Grand Rapids, Mich., primarily from the standpoints of hazard and protection instead of economics. In this case the voltage was somewhat higher, being 7,200 volts, the average span lengths were about 35 per cent longer, and more

open wire was used on the telephone facilities. The same general conclusion, that joint construction was the best engineering solution, was arrived at.

Additional studies are now under way, involving higher voltages and other conditions, and even though it is too early to predict the outcome of these studies it appears that a satisfactory general solution involving joint construction will be found as the answer.

Study of these specific cases will in time clarify the fundamental requirements that both utilities must meet before general joint construction at the higher voltage can be freely employed. Even at the present time we can agree that the power utilities should provide speedy disconnection of their circuits when contacts occur. Of course this also implies adequate grounding of the communication facilities and protective devices.

In this area the operating companies distribution voltages are largely 4-kv 4-wire and 11-kv 4-wire. The connection of new loads to 4 kv circuits in time makes it necessary either to construct additional 4-kv feeders or to change the voltage on existing 4 kv circuits to 11 kv. Sometimes the additional 4 kv circuit proves to be the more economical solution. In other cases raising the circuit voltage is by far the cheaper procedure.

In view of this, when we enter joint construction with 4 kv distribution lines we should know that ultimately we can stay in joint construction if the load conditions increase to such an extent that the 11 kv circuit is necessary. Using joint construction at 4 kv and later building separate lines if the voltage needs be increased to 11 kv is certaintly not a satisfactory answer.

The paper under discussion illustrates this point very definitely. If joint construction at 6,900 volts had not been successfully worked out in this case then the choice would have been between 2,300 volts with joint construction or 6,900 volts with separate lines. The 2,300 volt system with joint construction would probably have proved to be the more economical, even though the paper doesn't discuss this possibility, and in this event the $571,000 of potential saving in investment and a 24,000,000 kilowatt-hour reduction in losses would have been lost.

I believe the 2 utilities, led by the joint subcommittee, will find a satisfactory general solution to this problem and in time establish the proper bases under which higher voltage joint construction can be safely and advantageously employed.

W. R. Bullard (Electric Bond and Share Co., New York, N. Y.) and **D. H. Keyes** (Bell Tel. Labs., Inc., New York, N. Y.): In the discussion by Ashworth several interesting points are raised which warrant further consideration. The question of the utilization of the 11,000 volt grounded wye system instead of the 6,900 volt delta received considerable discussion in the early stages of this study. The decision to use the 6,900 volt delta system was made by the engineers of the operating power company. They preferred this system because by so doing they could utilize a large amount of existing equipment.

The bonding of the telephone cable and the neutral of the distribution system introduces a series of new problems involving not only the protection features, but also questions of noise on the telephone circuits and electrolysis of underground cable sheath. Various phases of this problem are now under investigation and it is expected that it will be necessary to complete a comprehensive investigation of the entire subject before mutual agreement can be reached as to whether or not such a practice would be satisfactory.

In discussing the advantages of utilizing a grounded wye connection, Ashworth points out that this would make unnecessary the grounding bank. As brought out in Rubel's discussion, the amount of current which flows into the telephone plant when in contact with power conductors is one of the factors which enter the problem of relative safety. The grounding bank introduces current limitation which generally is not obtained when the system is operated wye grounded. The methods to be employed for equivalent safety for a wye grounded system are being studied.

The committee is actively engaged in studying all of the factors which enter into the problem of safety for the different kinds of plant involved and has been continuously confronted with the necessity for a different treatment of cases which involve open wire as compared with those which involve cable only.

The Expulsion Oil Circuit Breaker

Discussion and author's closure of a paper by A. C. Schwager published in the July 1934 issue, pages 1108–15, and presented for oral discussion at the management and protective devices session of the Pacific Coast Convention, Salt Lake City, Utah, September 4, 1934.

D. C. Prince (General Electric Co., Philadelphia, Pa.): The general drift toward explosion chambers of one sort or another is a fine tribute to the foresight of such pioneers of the oil circuit breaker industry as E. W. Rice, Jr., E. M. Hewlett, and J. D. Hilliard. These pioneers were so prolific that it is difficult for any present-day engineer to produce a design which does not bear a strong resemblance to some vision of one of them. It is no discredit to Schwager that this is so in his case.

Figure 1 is a reproduction from a Hewlett patent application which was filed in 1910. This patent shows an explosion chamber with stationary segmental contact at one end into which the contact rod slides. The explosion chamber has 2 vents, as in Schwager's case. This stationary contact is located just outside the chamber through which the moving contact passes. In operation the moving contact is withdrawn into the explosion chamber setting up a blast through the vent adjacent to the fixed contact in a manner very closely resembling that described by the present paper. If Schwager's theory is accepted at its face value, the Hewlett design would be even better since it is not necessary to expel a block of oil before an active gas blast can take place.

Although Schwager's conception of the theory of operation of the explosion chamber differs from my own theory, the important fact is whether the design does or does not operate efficiently under practical conditions rather than whether it operates on one theory or another. However, it should be recognized that, as between 2 theories, some sort of critical test must be set up which would be expected to work differently depending upon which theory of operation actually represented what has taken place. For instance, in the tests at the Philo plant of the Ohio Power Company, Zanesville ("Circuit Breaker Field Tests," R. M. Spurck and H. E. Strang. A.I.E.E. TRANS., June 1931, pages 513–21, and *Electrical World*, Jan. 31, 1931), 2 forms of explosion chamber were compared, all other things being the same. In the first form a conventional explosion chamber was employed having a throat and hollow contact through which the oil in the chamber would be expelled. In the second form, an intermediate contact was placed in the explosion chamber allowing pressure to be generated so as to force solid oil out through the explosion chamber throat and contact. The tests were conducted with the same system set-ups and currents of the same order of magnitude. In 28 tests the plain explosion chamber showed an average arc duration of 8.6 cycles as compared with 3.5 for the oil blast in 40 tests under the same conditions. It is felt that this type of comparison is required if any valid conclusions are being drawn concerning the active element in interrupting the arc.

Schwager conclusively determines that the explosion chamber is very much superior to the open arcing between plain contacts as an arc interrupting means. His tests throw no light on whether the active agent is a gas blast or a more or less fortuitous oil blast. Various other conclusions drawn by him do not seem to be very well established. I do not feel that he has recognized the full achievement of the prior art in reducing arc energy when he states that 0.5 kilowatt-second per thousand kilovoltamperes is generally considered the best value obtainable. In the paper "The Oil-Blast Circuit Breaker," D. C. Prince and W. F. Skeats, A.I.E.E. TRANS., June 1931, pages 506–12, a record of 23 tests was given with values as low as 0.06 and an average of 0.18 kilowatt second per thousand kilovoltamperes. Such values are bettered in the performance of the high voltage impulse circuit breaker.

Noticeable oil deterioration would hardly be expected on the tests recorded. In Philo tests, Spurck and Strang recorded a series of 40 tests under conditions very much more severe than Schwager's in which the dielectric strength dropped only from 30 to 28 kv.

All of the interrupting tests reported by Schwager were single phase to ground tests with maximum recovery voltage of 65 kv. In an article "To Interrupt High Voltage in Three Cycles," D. C. Prince and E. W. Boehne, *Electrical World*, June 2, 1934, it was explained why it is that the first phase to clear a 3 phase fault has to clear a recovery voltage of 86.6 per cent of line to line voltage. For this reason it should have been necessary for Schwager's breaker to clear a 95 kv fault in order to demonstrate its ability to successfully interrupt a

110 kv circuit. These values are the rms 50 or 60 cycle components. A high frequency oscillation is superimposed on these values and may reach a considerably higher crest. The breaker under test may have been able to clear such a voltage, but it is felt that such evidence should be presented before a claim to that effect is made.

Most of the papers presented on oil circuit breakers for the past several years have referred to recovery voltage rate as one of the factors determining the difficulty in clearing a short circuit. It is generally considered not only in this country but abroad that the arc length and distress of the circuit breaker vary between wide limits as a function of this voltage recovery rate. In general, the recovery rate at the substation on a high voltage transmission line is quite low and the circuit breaker duty correspondingly light, while at the generator bus it may be high and the duty severe. Specific recognition of this fact was made in connection with the Philo tests which were deliberately carried out adjacent to the high power steam generating station for this very reason. It would be interesting to know what the effect upon Schwager's breaker would have been had high recovery rates been present. In the absence of such information, his comparisons of arc lengths with those reported in other tests are entirely meaningless. The Philo tests showed a difference of nearly $2^1/_2$ to 1 between the average arc duration as between 270 volts per microsecond and 2,400 volts per microsecond for the plain explosion chamber. With the oil blast contacts the ratio is less than 1.6 to 1. We see from this that the sensitivity of various forms of interrupting means to rate of recovery voltage rises may be quite different. High rates of rise may occur quite unexpectedly in the field and it is therefore a source of considerable assurance to an operator to know that his circuit breaker is not a "fair weather" circuit breaker capable of interrupting only the easier faults which may be thrown upon it, but that it will handle the most severe faults within its nominal rating. Such assurance cannot be given without more complete information than that provided in Schwager's paper.

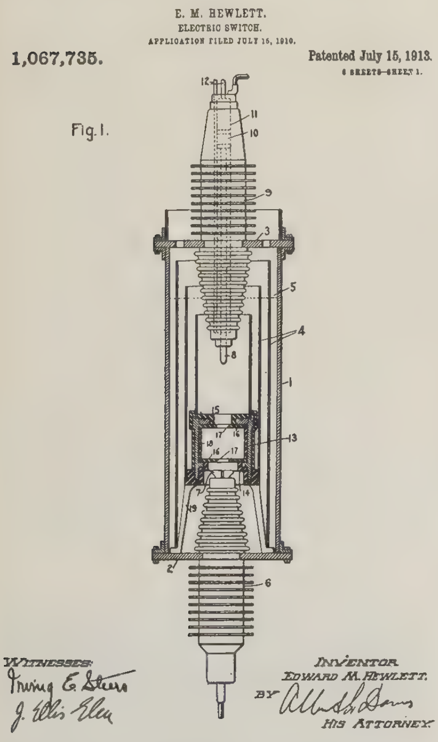

Fig. 1. Reproduction from a patent application filed in 1910, showing explosion chamber in an oil switch

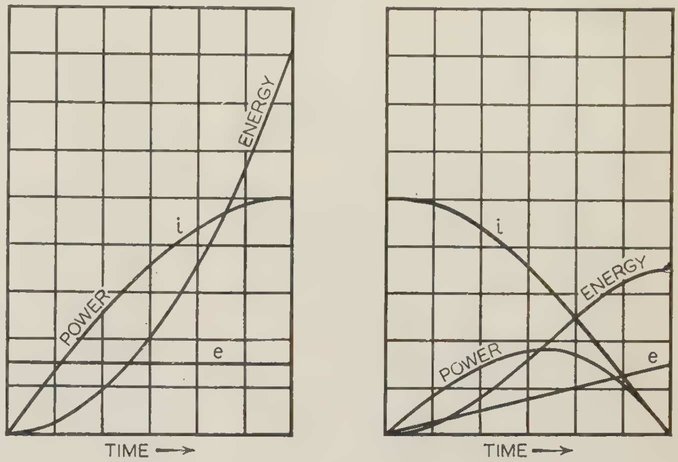

Fig. 2. Comparison of energy liberated in arc as computed under different assumptions

Curves on the left are drawn assuming current increasing from zero and arc voltage constant; those on the right are drawn assuming current decreasing to zero and arc voltage increasing

The question of the efficiency of various numbers of breaks in series has been a moot one for a number of years. Information is available ("Engineering Features of Oil Blast Action," D. C. Prince, *General Electric Review*, August, 1933) to prove that in the case of the high voltage impulse circuit breaker a number of breaks in series have an additive effect. However, that circuit breaker is particularly designed to provide a favorable distribution of potential among the different breaks. This condition is not generally met in the tank type breakers. Where it is not met, the effect of added breaks may be very slight or even negligible.

Figure 9 of the paper compares the arcing time of 3 and 6 explosion chambers. The times are in the ratio of 2 to 1.6 or a reduction of only 20 per cent in arcing by doubling the number of breaks. From table II and accompanying text it appears that the arcing time should be a half cycle or less, at least at 12 kv. Where 6 breaks provide a cumulative action, this short arcing time should be maintained to 6 times 12, or 72 kv. Obviously nothing of the kind has occurred, since the tests at 65 kv show over 3 times this much arcing, even with six chambers.

Recently a circuit breaker was equipped first with 2 and then with 4 explosion chambers of the very latest and most effective type and submitted to tests under precisely similar conditions. In order to eliminate the possible variations of individual tests, 3 tests were made with each arrangement. These tests were made at 220 kv and a recovery voltage rate of approximately 4,000 volts per microsecond. The average arcing time and length of arc with 2 explosion chambers were found to be 2.8 cycles and 7.9 inches per break, and with the 4 explosion chambers, 2.4 cycles and 7.3 inches per break. The 4 chambers thus show a gain of 14.3 per cent in arcing time and 7.6 per cent in arc length inches per break. The total average arc length was 15.8 inches for the 2 break design as against 29.2 inches for the 4 break design. Average arcing time of the 2 break breaker was 1.7 cycles at 132 kv. The arcing time of the 4 break circuit breaker at 220 kv would have been less than this, had the 4 breaks been dividing the voltage. The decrease in arcing time seems to be too small to justify the added complication of the extra parts required and increased oil deterioration due to increased arc length, and proves rather conclusively that the performance of the multibreak design cannot be found by multiplying the performance of the single break by the number of breaks unless there is some concrete evidence that such an operation is justified.

Incidentally, the 1.7 cycles average arcing time at 132 kv mentioned above was obtained with approximately 3,000 volts per microsecond recovery voltage rate, and compares with the average 1.7 cycles given by Schwager for his interrupting tests at only 65 kv and low voltage recovery rate.

It was fairly conclusively shown that the multibreak explosion chamber did not accomplish any useful purpose and certainly the conclusion cannot be safely drawn that where 3 explosion chambers will interrupt 65 kv, 6 would interrupt 220 kv or higher as claimed by Schwager. It seems probable that the 65 kv was actually interrupted by one explosion chamber of the 3. With 6 the performance would be substantially the same. This is not saying that 65 kv represented the limit of safe operation of the explosion chambers tested by Schwager. However, his data seem rather inadequate to support any prediction of the operation of a considerably higher voltage breaker.

It is probable that the designs discussed in this paper are capable of interrupting more voltage than that employed in the tests. The limit of recovery voltage rate was probably not reached and certainly not exceeded.

R. C. Van Sickle (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): In addition to presenting interesting developments in arc rupturing devices and demonstrating their superiority to plain breaks, this paper shows clearly the need for the

short circuit testing of circuit breakers. The organization with which the writer is connected has been designing and testing arc rupturing devices for a number of years and has found that even though a new arc rupturing device is designed with great care, some modifications will be indicated by the results of tests. It has also been found essential that the entire range of currents be covered by tests because in such devices there are 2 limitations which require consideration. The longer arcing times on low currents, when excessive, may lead to failure to interrupt. This type of failure is avoided by restricting the passages and thereby increasing the gas blasts. The other limitation occurs with heavy currents and is due to the pressures developed within the devices. Opening the passages relieves the pressure, but this affects unfavorably the performance at low currents. Therefore, the design is necessarily a compromise determined by the range of currents to be interrupted. The currents which are difficult to interrupt have been found in 2 ranges, between 300 and 500 amperes and at the maximum values. Since these characteristics have been found for a number of arc rupturing devices, including some similar to those described in this paper, it is probable that the characteristics hold for the expulsion breaker also. Consequently there is some question about the advisability of extrapolating the good results obtained between 960 and 3,600 amperes over the range from 100 to 10,000 amperes.

It is not clear just how much significance it was intended should be attached to the theoretical calculations of the oil piston motion. It is stated that because of the various assumptions which were necessary the results should be taken qualitatively rather than quantitatively. However, the first design had a calculated value of $\frac{V_0}{AH^3} = 0.36$ which was a reasonable tolerance over the calculated minimum 0.17. When the volume of gas generated was found to be less than the calculated amount and the resulting constant only 0.13, the device was not expected to operate in a quarter of a cycle. The next device had a constant of 173, probably indicating that the details were determined by other considerations.

The volume of gas generated being less than half of the calculated volume may possibly be explained by a review of the assumptions used in the calculations. The arc voltage was assumed to be constant during the first half cycle and it may have varied linearly starting at zero. The expression $E_t \cong E_0 \frac{(\omega t)^2}{4}$ for $o<\omega t < \frac{\pi}{2}$ is used for the energy, but it is based on constant arc voltage and is applicable for a quarter of a cycle just after a current zero instead of a quarter of a cycle just before a current zero. If the voltage is assumed to vary linearly from zero and the current to decrease sinusoidally from a peak to zero, the energy liberated, or the gas generated, is less than half of that calculated using the formulas in the paper. This is shown graphically in figure 2 of this discussion. On the left are the curves for the assumed conditions of constant arc voltage during a half cycle and the corresponding current, power, and energy curves. On the right are the curves with the suggested modifications. The arc voltage is shown for only a quarter cycle but its average for a half cycle is the same as the voltage used in the other set of curves. The current is shown for the quarter cycle preceeding the first current zero after contact separation. The power and energy curves are obtained graphically from the current and voltage curves. The energy calculated in this way is less than half of that obtained with the other assumptions and this ratio is about the same as the ratio of experimentally measured gas volume to calculated gas volume given in the paper.

The results obtained with these devices on the 110-kv field tests are very satisfactory and indicate a very good beginning for a line of modern circuit breakers.

A. C. Schwager (Pacific Electric Mfg. Corp., San Francisco, Calif.): It is realized that in a paper combining the descriptions of 3 major items, namely, theory, construction, and field tests, of a new oil circuit breaker development, it is necessary, due to space limitations, to omit from discussion many features which in a longer paper would be well worth mentioning. I therefore greatly appreciate the opportunity given me by Prince and Van Sickle to discuss in detail some of the items which due to their secondary importance had to be omitted.

First of all I thoroughly agree with Prince in the credit which he gives the early pioneers. One cannot help but admire their accomplishments, for 30 years ago they gave us fundamental designs which with practically no important alterations determined the general trend in circuit breaker design until a few years ago. Hewlett, as early as 1904, has shown that a blast of oil directed at high velocity across the arc shows excellent rupturing ability. Even before the oil circuit breaker was invented, Elihu Thompson in 1892 showed that arc interruption can also be accomplished by subjecting the arc to a high velocity gas blast. Although his design was later abandoned, it has during the last few years been reapplied abroad. Switches based on the air blast principle show remarkable performance, since they can interrupt short circuits up to 220 kv in a half cycle. It is easily seen why I have chosen for a starting point the ingenious method of arc interruption first proposed by him. The disadvantage of these air blast switches is, of course, the necessity for a ready supply of arc-extinguishing gas. However, if the Rice and Hewlett design, which makes use of the energy liberated in the arc to extinguish it, is combined with the Elihu Thompson gas blast principle, an expulsion type of arc interrupter is obtained which has all the remarkable features of the air blast switch. Although both the Hewlett and Thompson principles were previously used independently, it is believed that the expulsion circuit breaker makes use for the first time of a combination of these 2 principles and can therefore be expected to have quite different and improved characteristics when compared to the original Hewlett type switch.

In a comparison between the Hewlett switch and the expulsion oil circuit breaker, Prince states: "the Hewlett design would be even better since it is not necessary to expel a block of oil." The accumulation of a large quantity of gas during the time required for the removal of the oil piston is one of the fundamental features of the expulsion oil circuit breaker. Only in this manner can most economical use be made of the gases generated during the arcing period for the extinction of the arc. In the Hewlett switch the gases can escape immediately upon contact separation, a violent stream being directed throughout the arc during the entire cycle. This gas stream is of no purpose while the current flows at or close to its maximum value, since interruption at that instant is neither possible nor desirable. Due to the steady escape of gases during the entire half cycle, the gas stream at the moment of current zero will be many times weaker than one which is initiated near current zero after a period of accumulation of arc gases. Therefore, in an expulsion breaker the gas blast at the instant of the first current zero will be sufficient for interruption, whereas in the Hewlett switch interruption due to the weaker extinguishing action will not occur at such an early moment. The question as to whether the active agent is a gas blast or a more or less fortuitous oil blast has been carefully investigated by means of cinematographic studies of interruptions by expulsion contacts installed in a glass tank. By measuring the small volume of oil within the expulsion chamber (less than 1 cubic inch) and the large volume of gas escaping through the expulsion tube, the oil content of the extinguishing mixture was determined to be in the order of a few per cent of the total volume of gases generated. For this reason it is difficult to explain the action of the expulsion chamber on a well defined solid stream of oil.

The value of 0.5 watt second per kilovoltampere interrupted was chosen from "The Use of Oil in Arc Rupture," B. P. Baker and H. M. Wilcox, A.I.E.E. Trans., April 1930, pages 431–41, and of course applied to kilovoltampere values which approach the full rupturing capacity of the breaker. For smaller currents, such as Prince refers to, our values agree closely with his, averaging slightly less than 0.2 watt seconds per kilovoltampere. The expulsion oil circuit breaker, however, is capable of producing such a low ratio not only for small currents, but for currents up to maximum rated interrupting capacity. The best method of determining the superiority of one switch over another with approxi-

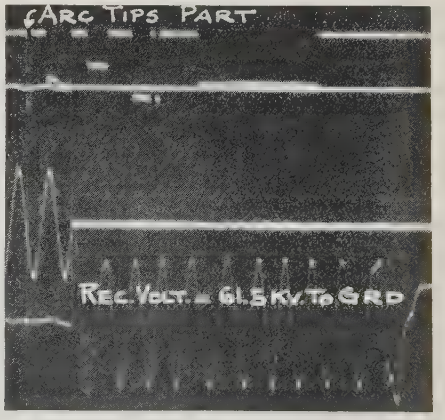

Fig. 3. Oscillogram of recovery voltage

mately equal arcing times is by a comparison of the arc voltages on oscillograms. Since I have not been able to find published data of arc voltages as small as that shown in figure 11 of my paper for currents in the order of 10,000 amperes, I believe that it is safe to assume 0.5 watt second per kilovoltamperes a fair value of the status of the previous art.

The writer is, of course, familiar with the excellent paper "Circuit Breaker Recovery Voltages," R. H. Park and W. F. Skeats, A.I.E.E. TRANS., March 1931, pages 204–38, on circuit breaker recovery voltages. The recovery values listed in table IV of the paper refer to the voltages appearing a few cycles after interruption and not to the first recovery voltage wave. Since the recovery voltages (60-cycle rms values) in the single phase ground tests reached values as high as 1.5 times line to ground voltage, most of these tests are actually an indication of the performance of the breaker at 110 kv. A recovery voltage of approximately 84 kv is shown in the oscillogram, figure 3 of this discussion corresponding to test number 2, table IV; the theoretical value on the basis of Prince's calculations amounts only to 60.5 kv. Since on the larger part of these single phase tests, performed on a practical high voltage system, the first half cycle of the recovery voltage was greatly in excess of the voltage before the short circuit, extreme caution has to be used in attempting to predict performance on the basis of theoretical calculations alone.

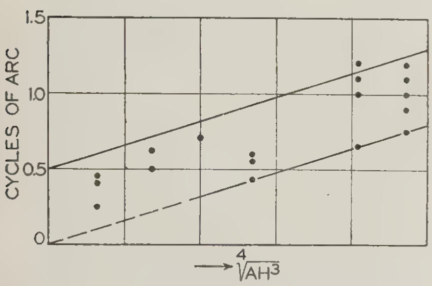

Fig. 4. Relation between arcing time and oil piston dimensions

Being associated with the manufacture of multiple break switches, I have been doubtful as to the claims of manufacturers of this type that the performance could accurately be determined from that of a single contact, until this statement was sufficiently proven. In my opinion, the tests by Sporn and St. Clair ("Tests on High and Low Voltage Oil Circuit Breakers," A.I.E.E. TRANS., volume 46, 1927, pages 289–311) on a high voltage multiple break switch have given ample proof of the correctness of this theory. The multiple break switch tested by them gave excellent service, each contact apparently contributed equally to the interruption. In conjunction with our plain 6-break switch tests shown in figure 9 we have performed 2-break tests under identical conditions and obtained arcing times varying from 20 to 25 cycles. The superiority of the multiple break principle, therefore, seems to be sufficiently established by tests.

Prince states that on the high voltage impulse breaker favorable use can be made of multiple break. To influence recovery voltage distribution use is made of electrostatic shielding. Such electrostatic shielding could, of course, most easily be applied to our 6 expulsion contacts, if it were necessary. There is unfortunately a fundamental error involved in assuming that the electrostatic capacitance alone determines the distribution of the recovery voltages appearing across the various contacts. Tests by Kopliowitch (Schweizerischer Elektrotechnischer Verein *Bulletin*, 1932, figure 10) show that the most radical attempt to influence the voltage distribution across a breaker is futile. Apparently the space charges surrounding the remainder of the arc path are so predominant that the effect of the electrostatic field disappears entirely. If the recovery voltage were a function of the electrostatic field alone, then it should be the same for various rupturing devices tested under identical circuit conditions. It has been shown, however ("Arc Extinction Phenomena in High Voltage Circuit Breakers," R. C. Van Sickle and W. E. Berkey, A.I.E.E. TRANS., Sept 1933, pages 850–7) that space charges within the breaker can modify the rate of rise of recovery voltage in a ratio of 1 to 10. R. M Spurk and W. F. Skeats ("Interrupting Capacity Tests on Circuit Breakers," A.I.E.E. TRANS., Sept. 1933, pages 832–40) have also found that the recovery voltage distribution is equal across the contacts under conditions which are certainly present in the expulsion breaker.

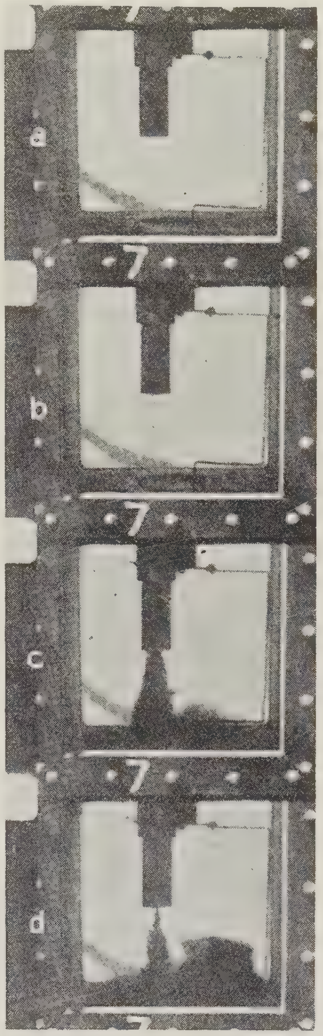

Fig. 5. Camera record of expulsion oil circuit breaker interrupting 175 amperes at 12 kv

Table I

Amperes Interrupted at 12 Kv	Arcing Time, Cycles	Amperes Interrupted at 12 Kv	Arcing Time, Cycles
200	1.0	980	0.7
220	1.0	1910	1.0
380	1.0	3600	1.0
600	1.0	3710	0.9

With such available test data and theoretical considerations it can safely be stated that equal voltage distribution exists in a multiple break expulsion oil circuit breaker. The fact that only a slight difference in arcing time exists between our 3- and 6-break tests has no direct relation to the number of breaks. If a single chamber is designed to initiate a gas blast say in one cycle, then it will not be possible to reduce this time by the use of multiple breaks, since each chamber requires at least one cycle for the establishment of its gas blast. The same explanation applies for the 220 kv test performed by Prince on 2- and 4-explosion chambers.

The lack of space available prevented a more thorough description of the test set-up and there is just cause under these circumstances to call the breaker a "fair weather" breaker. However, care was taken to obtain the most severe conditions of recovery voltage rise. Two synchronous condensers with a total capacity of 50,000 kva located at the Newark substation were connected in all cases and in tests 1 and 6, table IV, represented the only power source. The combination of these 2 condensers, an 11 to 110 kv transformer, the high side of one phase grounded directly through the test breaker, and a single 4-mile open line for measuring voltages allows an accurate calculation of the rate of rise of recovery voltage, giving a value slightly in excess of 1,000 volts per microsecond. With equal voltage distribution theoretically assured, the tests on 3 expulsion contacts with this set-up show that a 6 break expulsion breaker will interrupt a 110-kv 3-phase short circuit with 2,000 volts per microsecond rise in less than 2 cycles. Therefore, the assumption of performance under the most severe system conditions is amply justified.

Van Sickle points to the difficulty encountered with some arc rupturing devices when rupturing currents in the range between 300 and 500 amperes and suspects that similar performance might have to be expected with expulsion oil circuit breakers. Although test number 5, table IV, partially disproved this assumption, additional 12 kv tests on a single expulsion chamber were performed to investigate its performance in this critical range. The results are given in table I of this discussion, showing a uniform arcing time.

The importance of such small arcing times in the low current range is an outstanding feature of this device. Whereas a breaker with a highly increased arcing time within this range can cause oil carbonization due to a few normal switching operations, equally or more severe than that due to a heavy short circuit, the expulsion breaker is free of this disadvantage.

In the limited space available only 2 contacts were investigated to demonstrate the influence of the dimensions of the oil piston upon the arcing time and I thoroughly agree with Van Sickle that they alone cannot conclusively prove the theory outlined. Additional tests in which the dimensions of the oil piston were more gradually varied have been performed and will be discussed in the following.

In the paper it was assumed that the arc energy and correspondingly the gas volume increase in quadratic relation with time. The assumption of constant arc voltage and contact separation at current zero led analytically to this relation in the simplest manner. As brought out by Van Sickle and confirmed by our tests, the arc voltage in an actual circuit breaker whose contacts move at constant speed increases linearly, in fact almost proportionately with time. The gas generation for contact separation at current zero as well as current maximum can be approximated by a quadratic law, the rate for separation at current maximum being approximately twice that for separation at current zero. The value $V_t \cong V_0 \dfrac{(\omega t)^2}{4}$ used in equation 3 represents approximately the average of these 2 conditions. Writing equation 9 in a more general form results in:

$$\omega t_0 = \text{const} \sqrt[4]{\frac{AH^3}{V_0}} \tag{9a}$$

where t_0 represents the time required for the initiation of a gas blast. Interruption of the current takes place at its next current zero and depending upon the instant of contact separation will result in an arcing time lying in a range between t_0 and $t_0 + \dfrac{\pi}{\omega}$. From equation 9*a* it can be seen that for the 2 extreme cases with a ratio of 2:1 in the rate of gas generation, the respective times t_0 will differ less than 20 per cent. With the average rate of gas generation used in equation 3 of the paper, the values ωt_0 for any particular contact separation are likely to be within 10 per cent of the calculated value. A different rate of gas generation, instead of being brought about by a different instant in contact separation, can be produced by a change in current. It can be expected that currents producing arc energies not varying in excess of 2:1 will have the same negligible influence upon t_0.

Several expulsion chambers with various values of $\sqrt[4]{AH^3}$ were built and tested at 12 kv, interrupting currents from 1,000 to 3,500 amps. Figure 4 of this discussion shows the relation between arcing time and $\sqrt[4]{AH^3}$. All test points lie in a zone of a width of $^1/_2$ cycle, the lower boundary line of the zone of which the arcing time is identical to the expulsion time establishing the approximately proportional relation predicted between ωt_0 and $\sqrt[4]{AH^3}$. The expected small influence of a variation in V_0 due to instant of contact separation and current value is well confirmed.

The fourth root relation between ωt_0 and V_0 allows a theoretical interpretation of the uniform performance of the expulsion contact over the entire current range. Assume the expulsion time for maximum current to be $^1/_2$ cycle, the expulsion time will be less than 1 cycle as long as arc energy and gas generation are not reduced to less than $^1/_{16}$th of the original value. Since such a large reduction between maximum current and currents in the order of 300 to 500 amperes is not experienced in the expulsion breaker, performance can be expected to take place with a variation in arcing time not exceeding $^1/_2$ cycle, a conclusion which is experimentally proved in table I.

In an endeavor to verify all phases of the interruption in an expulsion chamber, such as oil expulsion, gas blast, and interruption, we employed a method which also enabled us to estimate oil velocities. An expulsion chamber was mounted in a glass tank, the opening of the expulsion tube being directed toward the bottom of the tank, and the movable contact withdrawing in an upward direction. Figure 5 of this discussion shows an interruption of 175 amperes at 12 kv. Frame *a* shows the lower end of the expulsion tube preceding contact separation; in frame *b* the arc is established and the oil piston which is clearly visible has almost completely left the tube. In frame *c* the high velocity gas blast is established and the current is interrupted as can be verified from the following frame *d*. These pictures were taken at the relatively slow speed of 64 per second, but they prove the correctness of the expulsion theory developed and besides allow a calculation of the oil velocity. The average velocity in the case shown exceeds 60 feet per second. If higher camera speeds were employed, it would not be difficult to measure instantaneous oil velocities with a fair degree of accuracy.

Distance Relay Action During Oscillations

Discussion and authors' closure of a paper by E. H. Bancker and E. M. Hunter published in the July 1934 issue, pages 1073–80, and presented for oral discussion at the management and protective devices session of the Pacific Coast convention, Salt Lake City, Utah, September 4, 1934.

W. A. Lewis (Westinghouse Elec. and Mfg. Co.. E. Pittsburgh, Pa.): This paper is the first analytical study of the action of distance relays during oscillations, although the action of these relays under fault conditions with various connections has been previously analyzed. (Fundamental Basis for Distance Relaying, W. A. Lewis and L. S. Tippett. ELECTRICAL ENGINEERING, July 1931, page 420–1.) In the paper it is assumed that the oscillation takes place only after the fault is cleared, or, in other words, that the fault and the oscillation are not present simultaneously. Unfortunately, this state of affairs is realized all too seldom. Normal switching and relaying on a well designed system are arranged so that the system will remain stable for a severe fault in the worse fault locations and with maximum load. Since these combinations occur infrequently, most faults do not occur under the most severe conditions, and a severe swing seldom results unless a fault is not cleared in the anticipated time. The failure to clear may be due to the absence of suitable relays to clear rapidly the particular fault encountered, the temporary removal of equipment from service, or to some defect in the equipment or control power. As an example, the cases cited in the discussion by Gerrell (ELECTRICAL ENGINEERING, Sept. 1934, page 1320.) may be pointed out, in which the faults causing interruptions were at such locations that the high speed relays had no opportunity to clear the fault. In such cases we have to content with the fault and the oscillation simultaneously, and relays which may operate correctly for either condition alone may trip undesirably when the 2 conditions occur simultaneously. The analysis of this case is much more difficult but is fully as important as the case analyzed by the authors. If one line fails to clear in the anticipated time it is very important that other lines should not trip incorrectly if it is possible for synchronism to be maintained.

The device which is most particularly affected by presence of a fault during an oscillation is the starting element of the reactance relay. As shown by the curves in the paper, when there is no fault the power factor near the electrical center, where the voltage is low, is such that the relay torque is low and a large current is required for operation of the starting element. When the fault is also present, the voltage is further reduced and the addition of fault current reduces the power factor, so that the starting elements will operate at a much smaller total current. This is to be expected, since the starting element should operate in the line sections near the fault whenever a fault occurs. However, under such conditions the starting element is of no value in preventing tripping during the resulting oscillation, and reliance must be placed in the ohm unit alone. In the paper the conclusion is reached that reactance relays close to the electrical center will have less tendency to trip during an oscillation than impedance relays in the same location. However, it is the starting element which prevents tripping, and if the fault is present simultaneously this conclusion cannot be maintained.

To bring out the details, a simple example has been investigated, as shown in figure 1 of this discussion. The system is the same as that considered by the authors except that a fault has been added with impedance in series. As far as the effects on relays external to the faulted section are concerned, this is equivalent to a fault between bussing points on the tie line, or to a fault at some location in the receiving-end system which is not immediately associated with the tie. If the fault should be a 3 phase fault, it is easily conceivable that it will produce a severe oscillation if not cleared rapidly, and yet this location may readily be one which is not protected by high speed relays. The location of the fault branch has arbitrarily been taken as 20 per cent of the distance toward the receiver from the electrical center of the system without fault, and the impedance in series with the fault has been taken equal to the impedance between the center and the point of fault application. The relay station considered has been taken as 5 per cent toward the sending end from the center. The current required to operate the various relay elements for several settings as a function of the displacement angle is given in the

figure. The curve notation is the same as given in the paper, page 1079. It will be noted that curve C, which shows the current required to operate the starring element of the GCX relay on the $12A$ tap, is now very small for any angular position, and less than that required to operate the distance element, except for the 8 ohm setting, which is seldom, if ever, used. The dashed curves K, M, O, and P show the current required to operate the impedance relay when set on the 2, 4, 6, and 8 ohm taps, respectively. The solid curves E, G, I, and J show the current required to operate the ohm unit of the reactance relay when set on corresponding taps. It will be noted that in the region from 90 to 130 degrees, as covered by the paper, figures 8 to 12, inclusive, about 20 per cent more current is required to operate the impedance relay, and in consequence there is less danger of incorrect tripping. The relay location is within the zone which is more favorable to the reactance relay when there is no fault, but this same location becomes unfavorable to the reactance relay when the fault is present.

In connection with the discussion by Bancker and Hunter (ELECTRICAL ENGINEERING, Sept. 1934, page 1322). I assume that the equations give the current for unit voltage and that they should be multiplied by 115 to give the current for full voltage. At least this appears to check the values given in the figures. It is probable that greater approach to actual conditions will be obtained by the use of a higher figure, since this voltage is supposed to be proportional to the internal voltages of the machines, but there is some doubt as to what value should be used, and the use of 115 provides a factor of safety.

E. H. Bancker (General Electric Co., Schenectady, N. Y.): To consider the problems raised in Lewis' discussion would require a study of at least 27 different sets of conditions. Fortunately many of these may be grouped and others may be disposed of briefly.

The 3 original conditions which may exist are:

1. Fault originally beyond the back-up zone.
2. Fault in the back-up zone.
3. Fault in the intermediate zone.

The 3 types of relays under discussion are:

1. The GAX reactance distance relay.
2. The GCX reactance distance relay.
3. The 3 step impedance relay.

The progress of the swing following the start of the fault may lower the ohmic indication to the various types of relays to:

1. The back-up zone.
2. The intermediate zone.
3. The instantaneous zone.

If the fault originally lay beyond the back-up zone and the action of the system oscillation was to lower the ohms to a value which caused the starting unit or back-up impedance element to operate, it should be remembered that the indicated ohms must stay within this setting long enough for the back-up time to expire before tripping will occur. While this is possible, it indicates a lack of adequate relaying elsewhere on the system, since the fault must persist for the total duration of back-up time plus whatever time it took for the swing to bring the initial indication from outside of the back-up zone to within it. As ordinarily set, this would mean that the fault duration was anywhere from 2 to 6 seconds and indicates that the relaying of lines

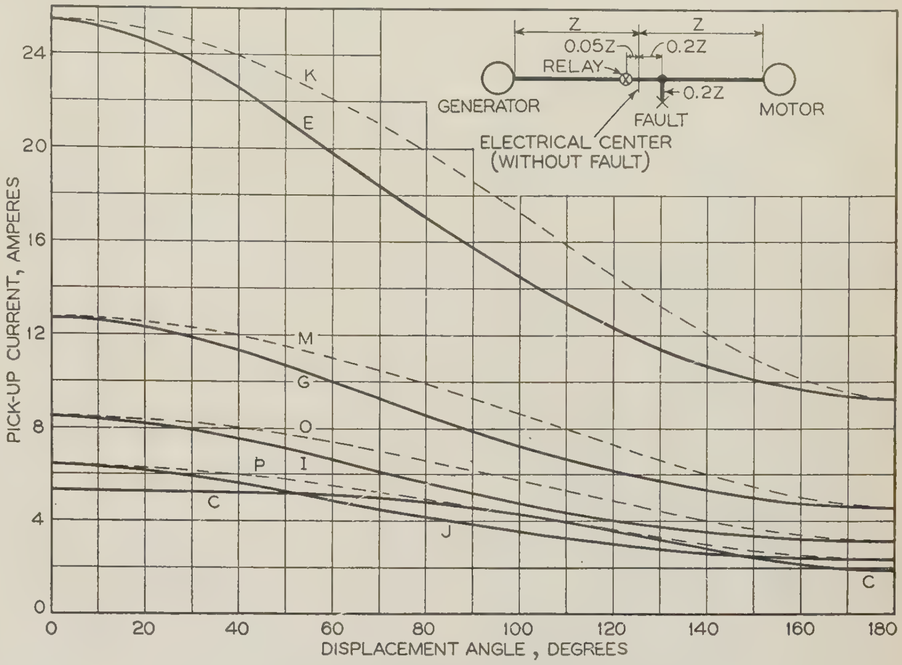

Fig. 1. Relay characteristics with fault on system

immediately adjacent to a section subject to oscillations should be coördinated to avoid false tripping. Another possible remedy would be the use of a lower ohmic setting for the back-up element. The requirements of this element are that it must operate surely for any and all faults within the section protected by the relay. If it is possible to utilize a lower ohmic setting for the back-up element of the impedance relay, it is equally possible to go to a higher current setting for the reactance relay starting unit since the requirements for the 2 elements are the same.

A fault originally beyond the back-up zone which initiates a swing, bringing the indicated ohms down to the intermediate zone, is even less likely to occur within the allotted time than the case just considered. In order to reach intermediate zone, the back-up zone must first be traversed and intermediate reached before the expiration of intermediate time or none of the 3 types of relays would trip. In other words, if intermediate ohms are indicated after intermediate time has expired, the relay does not trip until back-up time is reached.

It is obviously still more improbable that the ohmic indication for a fault which was initially outside of the back-up zone will ever become as low as the instantaneous distance so that this case is probably of no practical importance.

Coming now to those faults which start as though in the back-up zone, if they continue to indicate this same distance for the duration of back-up time, all the types of relays will, and should, trip. Any such condition as this is probably an improper application of relays because the fault should not persist for this length of time or selectivity cannot be secured. The other possible causes are that some breaker and relay failed to clear in its allotted time and back-up action was required, which again is correct action for the relays.

The third alternative is the possibility that the fault did clear, but that the swing had progressed enough to keep the starting element and back-up impedance elements from resetting. In this last case the action can be studied from the curves of the paper, since it involves a swing without any fault and in this case reactance relays near the center are less susceptible than impedance relays, while the reverse is true at the more remote points.

The GAX relay cannot operate in intermediate time once it has indicated back-up distance and hence, should the swing change an initial fault within the back-up zone to one indicating in the intermediate zone, the relay will not trip until back-up time, and, as before, a fault persisting this length of time indicates that something is wrong elsewhere on the system.

Similarly, if a fault swung down to the instantaneous zone, the GAX relay might be prevented from tripping merely by the change of one internal lead. In the standard relay, instantaneous tripping is not prohibited after having indicated back-up distance, but if desired could be provided by opening the instantaneous contact with the transfer relay that opens the intermediate time contact. This case, however, is a rather infrequent one since it would require a large change while the fault exists. It is much more likely to occur if the fault should clear but leave the starting unit picked up since the ohm unit would then probably indicate very low ohms and trip immediately.

With the GCX type of relay, an oscillation must progress fast enough to bring the ohms from an initial value in the back-up zone, down to the intermediate zone, before the expiration of intermediate time after

the start of the fault, or the relay cannot trip because of the passing contact used for intermediate time. The likelihood of an oscillation producing such a major change in ohms in such a short time is somewhat remote. The statements made with reference to the *GCX* also are applicable to the impedance relay, which as Lewis states has a somewhat lesser chance because of the higher indicated ohms caused by a simultaneous fault and oscillation.

The chance of an oscillation changing from back-up to instantaneous ohms is so remote that it is not considered of great importance. However, the *GCX* cannot trip instantaneously even when this occurs, because shortly after the starting unit has first operated, the instantaneous trip circuit is opened. This type of relay can only trip immediately after the starting unit contacts have closed, for a few tenths of a second at intermediate time, or at the back-up time.

The remaining cases of faults which initially start within the intermediate zone and then stay there or swing down to the instantaneous zone have no great significance. If a fault occurs within the intermediate zone and stays there for intermediate time, it should be tripped by the relay under study. Should the swing bring the indicated ohms into the instantaneous zone, it is a fairly conclusive indication that some other relay has failed to perform as anticipated because any fault which was initially in the intermediate zone of some relay must have been in the instantaneous zone of some other relay if the relays were properly applied. Hence, correct relay and breaker action would prevent the possibility of a simultaneous fault and swing of this nature. This case is also very unlikely to occur since the chance of a swing reducing the ohms from intermediate to instantaneous within intermediate time, when the relay would trip anyway, is very remote.

From these considerations it becomes evident that while the starting units of reactance relays near the electrical center are not as immune to a simultaneous fault and oscillation as they are to a plain oscillation, there is no reason why they cannot be set to compare favorably with impedance relays since their functions are similar. It should also be noted that the most likely cause of misoperation requires that the indication be for a fault within the back-up zone for something longer than back-up time. While it is entirely possible that swings may be slow enough so that this could occur, it is not believed that it is a very likely occurrence nor is it believed good practice to permit faults upon any circuits adjacent to an important tie to persist for this length of time. Hence, the most disturbing case of possible trouble can be corrected by the proper application of relays in the immediate vicinity of sections prone to oscillate.

In a previous discussion by the authors (Electrical Engineering, Sept. 1934, page 1322) the equation given for the operating current is for 100 volts. As Lewis states, it should, therefore, be multiplied by at least 1.15 upon the assumption that 115 is the nominal system secondary voltage. The additional drop within the machines is, as he states, somewhat of a safety factor because the actual internal voltage of the machines is higher than the nominal rated voltage.

Lightning Investigation on a 220 Kv System

Edgar Bell, Aug. 1934 issue, p. 1188–94.

Theory and Tests of the Counterpoise

L. V. Bewley, Aug. 1934 issue, p. 1163–72.

Counterpoise Tests at Trafford

C. L. Fortescue and F. D. Fielder, July 1934 issue, p. 1116–23.

Lightning Investigation on Transmission Lines—IV

W. W. Lewis and C. M. Foust, Aug. 1934 issue, p. 1180–6.

Lightning Performance of 132 Kv Lines

Philip Sporn and I. W. Gross, August 1934 issue, p. 1195–1200.

Discussions of papers presented for oral discussion at the session on lightning at the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

P. L. Bellaschi (Westinghouse Elec. & Mfg. Co., Sharon, Pa.): The field investigations during the past 3 lightning seasons have enhanced materially our previous knowledge of lightning stroke phenomena. The mechanism of the lightning stroke formation has been studied most effectively by means of the "rapid" camera.[1] In the laboratory lightning stroke currents have been produced for the first time[2] and from first hand studies of lightning currents in the laboratory during these past $1^1/_2$ years, valuable data on lightning phenomena have been obtained. New and improved methods[2,3,4] for determining lightning currents have been applied in the field. From these improvements a more accurate determination of lightning currents has been possible lately than was possible before.

More remains to be done, however. Direct measurements of the lightning stroke potential and current with the cathode ray oscillograph are obviously very desirable. Such measurements could be accomplished by intercepting the lightning stroke before it strikes earth with a conductor elevated above ground, either with a kite or a balloon or other means. While these investigations appear to be of a scientific nature, they would undoubtedly establish more solidly the fundamental principles of lightning protection and they would, therefore, contribute beneficially to the engineering technique of protection.

The papers the writer wishes to discuss deal in particular with lightning as it affects the design and operation of transmission lines. Whether a transmission line is lightning proof or to what extent it is vulnerable to outages from lightning depends so much on a knowledge of the lightning stroke phenomena that it is of fundamental importance to compare the data on lightning presented in these papers with any other corresponding data obtained from similar and other sources. To limit this discussion to reasonable length I shall confine this critique to Lewis and Foust's paper which in a good measure reports and correlates the data obtained on the systems investigated by Bell and Sporn and Gross.

The importance of the lightning stroke as a source of disturbance on lines, as well as at substations, becomes more apparent from actual numerical figures on the frequency of occurrence. In comparing data from various sources it is well agreed that account must be taken of the line construction, topography of country in which each line runs, isoceraunic level or storms per year, and the lightning severity during the various seasons. This discussion does not intend to compare the various data to the last detail but rather its purpose is to emphasize once more the real importance of direct strokes in so far as these affect the continuity of service of overhead lines and may subject line and station apparatus to damage and even destruction.

Referring to the data on the 220-kv Wallenpaupack-Siegfried line, the 37.5 miles of the line with no ground wire protection gave 266 flashovers of towers in the 6-year period from 1928 to 1933. In this period the average lightning severity was 90. This transmission line lies in a territory where the isoceraunic level is approximately 35. On this line, then, lightning strikes on the average once per year per 0.85 mile of line.

Lightning investigations on a 60-mile telephone wood-pole line in Texas indicate that 35 poles were damaged during 1930. The average isoceraunic level in this case is approximately 40. On this particular line lightning strikes on the average once per year per 1.72 miles of line.

A survey made in 1927–28, by one company, on 811 miles of wood-pole lines, reveals the following interesting data.[5] The system consists of 66- and 33-kv pin type lines without overhead ground wires but with pole ground wires on 20 per cent of the poles. A detailed report was made of each pole which showed any sign of damage, regardless of its severity. Since 20 per cent of the poles were grounded the length of the exposed circuit is 650 miles. The total structures or poles involved numbered 213. This system covers a territory where the isoceraunic level is 80. On the average lightning strikes this system approximately once per year per 3 miles of line.

Two years field experience on a number of distribution transformers located throughout the country in exposed territory indi-

cates that each year approximately 0.5 per cent of such transformers are subjected to direct strokes of lightning.[6]

Without any attempt at correlating in detail all these data, it is apparent that the frequency of occurrence of direct strokes on high voltage, medium voltage, and distribution voltage systems is sufficiently great in all cases to warrant a consideration of the protection required or the relative risk incurred from direct strokes to lines, substations, and distribution transformers.

Measured values of lightning stroke currents in tower legs have apparently suffered a marked scaling down during the past 2 years. A comparison of the currents measured 2 years ago with the present data (tables I and II of this paper and table IV in a previous paper[7]) shows clearly that the earlier values must have been substantially too high, due possibly to the inductive lead effects vitiating the earlier measurements. The present measurements have been made with the crest ammeter magnetic link. A comparison is made in the following between the most recent tower currents reported by the authors and the data on lightning currents that have been obtained during the past 2 years and more by the writer.

Field experiences with direct strokes to distribution lines, radio antennas, wood pole ground wire, and other elevated objects constitutes the sources from which the data on lightning currents have been obtained by the writer. The lightning current in the path of a direct stroke may be determined in a number of ways. It may be determined from the physical effects produced when these effects are in turn evaluated in the laboratory by similar effects produced by artificial lightning stroke currents.[2] Analysis of the physical effects recorded will often enable predicting the lightning stroke current on the basis of fundamental considerations.

Experience with a large number of direct strokes of lightning to a wood pole line with pole ground wires in a territory subject to severe lightning indicates that no case has been recorded where the segment of No. 10 copper wire (which is used at the top of the pole) has been actually fused. Data have also been obtained by the writer with a direct stroke through a No. 10 copper wire of a radio antenna. Similar observations on radio antennas and direct experiments with lightning rods[2] indicate that the current in a direct stroke can be expected to fuse copper wires of No. 14 size and smaller, but that larger conductors will ordinarily conduct the current successfully to ground.

Field investigations with the cathode-ray oscillograph show a duration of the waves, produced on lines by lightning, of from 15 to 100 microseconds where time is measured from the start to the half crest value on the tail. Measurements of the light intensity of the stroke by Dr. B. F. J. Schonland indicate that the duration of the discharge is on the average 40 to 50 microseconds. However, his measurement also brings out that the wave form is characterized with a sustained peak on the crest that endures a fractional part of the duration. More remains to be known of the wave form and duration of the lightning stroke current but a duration of 40 to 50 microseconds on the basis of an equivalent exponential wave form seems reasonable.

Another consideration pertains to the repetitive nature of the stroke. A limited number of strokes consist of a single discharge, a greater number of 2 or more discharges, and again a limited number of a great number of discharges. It is an important fact that the first discharge is the most intense and severe while the successive discharges appear markedly reduced in intensity.[1] Considering the extensive experiences on the fusion of copper conductors produced by lightning, a reasonable number could have been produced by a single discharge or by a heavy single discharge followed by a markedly weak discharge.

Equations of the surge current required to produce fusion of various common conductors have been established[2] experimentally and analytically by the writer.

Let

$i = I_{(max)}\,\epsilon^{\frac{-0.693}{T}t}$ be the surge current discharge where

t = time in microseconds

$I_{(max)}$ = crest value of current in amperes

T = duration of current discharge from crest to half crest value

Then the current for a single lightning discharge that would produce fusion of a copper conductor is given by the following expression

$$I_{(max)} = 320{,}000\,\frac{A}{\sqrt{T}} \tag{1}$$

where A = cross-sectional area of conductor in square millimeters.

From equation 1 it is evident that a single lightning stroke discharge of 40 microsecond duration in order to fuse a No. 14 copper wire (1.63 millimeter diameter) must attain a current in the order of 100,000 amperes.

Field experience has also revealed valuable information on direct and nearly direct strokes of lightning at distribution transformers provided with deion gap protection.[6] The plugs or electrodes of the deion gaps discharging these heavy lightning currents were marked on the faces with a "surface figure" or "surface fusion." The "surface figures" when compared with similar figures obtained on deion gaps tested with known lightning currents in the laboratory were found to indicate that 0.5 per cent of the gaps discharged lightning stroke currents of approximately 20,000 amperes and greater. In 0.30 per cent of the cases lightning currents of 40,000 to 60,000 amperes and more were recorded. In one case recorded in 1934 where the lightning stroke hit right at the transformer, from all the evidence available properly correlated, a current of at least 100,000 amperes was discharged.

As additional evidence, it is well known that with direct or nearly direct strokes of lightning at distribution transformer installations, fuse cutouts and similar apparatus have been completely destroyed and shattered. Similar effects have been produced in the laboratory with heavy surge current tests.

One very interesting method for determining the lightning current consists in evaluating the crushing effect of a lightning stroke discharging through 2 conductors in parallel, an instance of which has been observed in the field. An analytical study of crushing effects would reveal very interesting data, but the analysis is unfortunately too lengthy to be reproduced adequately in this discussion. It is sufficient to say that a correlation of the crushing effect with a similar result obtained in the laboratory indicates that currents from 40,000 to 100,000 and possibly somewhat more at the worst may be expected in the field due to direct strokes.

The data in tables I and II reported by the authors indicate maximum tower currents of from 50,000 to 63,000 amperes. The total current discharged by the lightning stroke would accordingly be somewhat greater than this. Close to 50 per cent of the currents recorded are of 20,000 amperes or greater. Practically all the currents are of negative polarity; this fact establishes more firmly previous data indicating the prevailing frequency of the negative polarity strokes.

The method used to measure the tower currents in tables I and II is based on the magnetization of links of magnetic materials and their ability to retain the magnetization produced. The authors are no doubt aware that this method of measurement was perhaps the first one used in the very early days of lightning investigation some 30 years ago, when an attempt was made to estimate the maximum lightning stroke current discharged to earth.[8] With the modern refinements and facilities for calibrating these magnetic links, dependable data on lightning stroke currents should be forthcoming in the years to come. Other methods for determining the lightning stroke currents will no doubt continue to contribute an equal amount of valuable data. In the absence of direct cathode ray oscillograms of the lightning stroke current, it will be only through a correlation of all these data that dependable values of the magnitude and duration of the lightning stroke currents can be established.

The data in figures 1 to 4 give specific information on traveling waves appearing at a point on the Wallenpaupack-Siegfried line and at the Wallenpaupack substation. From these data it is reasonable to expect that "at the end of the line the waves may reflect and increase in voltage."

From the standpoint of stresses imposed on the 220-kv station apparatus only reflected waves greater than 400 kv need be considered. This substation was then subjected, in the course of about one year, to 10 surges in excess of 400 kv. Five of these surges are of positive polarity and average about 600 kv; the other 5 are negative and average about 800 kv. The negative surges are on the whole of higher voltage than the positive. The highest surge is a negative surge reaching a value of 1,270 kv in 3.3 microseconds, where it was chopped, presumably by the "spillway" gap at the substation. The duration of the front of 9 of these surges is from 3 to 10 microseconds, the tenth surge having a 38 microsecond front. The duration of the tail of 9 surges, measured from zero to half crest value, is 15 to 40 microseconds. One surge indicates a duration of about 70 microseconds.

These field data on traveling waves confirm once more the adequacy of the $1^1/_2 \times$ 40-microsecond wave used to test apparatus in the laboratory, as it simulates traveling waves as they appear on lines and at apparatus in actual service.

The data in figures 1 to 4 also show that 80 per cent of the traveling waves are of positive polarity, the bulk of which are from

100 to 500 kv. Since it is definitely established that direct strokes are predominantly of negative polarity, these data apparently indicate that the bulk of the positive waves originate from the induced effect of lightning. A consideration of the amplitude of the positive waves shows that while induced voltages may be practically inconsequential on 220-kv lines, they may assume a certain importance on medium voltage and particularly on low voltage lines.

References

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7. Lightning Investigation on Transmission Lines—III, W. W. Lewis and C. M. Foust. A.I.E.E. Trans., June 1933, p. 475–81.
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J. H. Hagenguth (General Electric Co., Pittsfield, Mass.): The results of tests described by Bewley and Fortescue and Fielder are in general very similar. The voltage induced on the line wire when the ground wire alone was connected is 23 per cent in one case and 24 per cent in the other. This of course is to be expected, since the spacing of the 2 lines is approximately the same in both cases, also the height above the earth's surface. Also, the induction on the line wire when both the ground wire and the counterpoise were connected in both tests is of the order of from 27 to 32 per cent. The impedance of the buried counterpoise was found to be a function of time. This was also found in previous tests made in Michigan. The data presented by Bewley undoubtedly shows the presence of multivelocity waves and therefore the proof of the existence of separate ground levels for current and voltage images. He experiences, however, the difficulty of determining the proper depths of these ground levels, similarly as Fortescue and Fielder. This discussion is an attempt to clear up some of these difficulties and reduce the problem of the counterpoise to a practical basis. The considerations following are based on the same tests described by Bewley.

Current Plane and Importance of Induction From Counterpoise

The induction on the line wire from a wave traveling on the counterpoise was found to be approximately 9 per cent by Bewley. It was stated by Fortescue and Fielder that they expect a greater percentage for greater depths of current plane. Since Bewley's calculation showed such good agreement with test results, his simplified equations (appendix *B*) were used to calculate the induced voltages on the line wire for various depths of current planes. In table I of this discussion h_3 is depth of current plane below a counterpoise spaced 1 foot above ground and h_2 is depth of plane below the line wire. The depth of voltage plane was assumed to be constant at H_3 = 2 feet below the insulated counterpoise. The ratio of induced voltage on the line

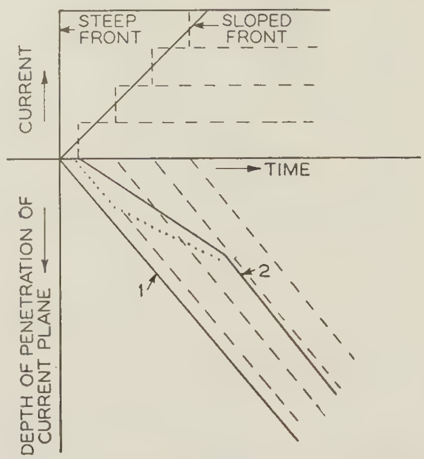


Fig. 1. Velocity of propagation of depth of current plane as affected by front of current wave
1. Steep front
2. Sloped front

wire to the applied voltage on the counterpoise is e_2/e_3.

Now it can be seen that the coupling factor e_2/e_3 increases very slowly as h_3 is increased and a value of 19.2 per cent is obtained at h_3 = 1,000 feet, i. e., the current image would be $2h_3$ = 2,000 feet below the counterpoise. But, as will be explained later, it takes about 6 microseconds before such a low depth is reached at the test location. It appears from this table in connection with the other data obtained during the tests that the voltage induced will hardly ever exceed 13 per cent (current image 400 feet below counterpoise) and usually will be less than 10 per cent, especially when the height of conductor above the earth's surface is increased above values given in the table. The induction from the ground wire on the line wire was found to be approximately 24 per cent in both papers. This induction, calculated on the basis of the usual electrostatic theory of multiconductor systems, will have about the same magnitude and it will increase considerably as the height of the conductor above the surface of the earth is increased. It can now be stated that the induction from the counterpoise is less than 50 per cent of the induction from the ground wire for low height of conductors and less than 25 per cent for very great conductor height.

In addition it should be noted from Bewley's figure 4, part I, that the voltage induced from the ground wire is 24 per cent, and from figure 11, part II, the voltage induced from the counterpoise alone is 9.8 per cent. However, when both ground wire and counterpoise are excited (figure 11, part III) the induced voltage is only 27.5 per cent. Thus the additional coupling contributed by the counterpoise was only 3.5 per cent. This is due to the reaction between counterpoise and ground wire when both are carrying currents and shows that the benefit from voltages induced from the counterpoise is indeed small.

There is, however, another and more important function of the counterpoise: that of reducing tower top voltages. If we assume a surge impedance of a ground wire as 500 ohms, the tower footing resistance as 400 ohms, and a counterpoise impedance of 100 ohms (ground wire and counterpoise 2-way) then the effective impedance Z_e of the ground installation is 37.7 ohms.

The surge impedance Z of the lightning stroke has been variously estimated to be between 200 and 400 ohms. The voltage of the tower top e_1 then would be

$$e_1 = E\frac{2Z_e}{Z_e + Z}$$

where E is initial lightning discharge. Using the 2 outside limits for values of the surge impedance of the lightning stroke, we get table II of voltages $(e_1 - e_2)$ across the line insulators, where e_2 is voltage induced on line wire.

From this table 2 principle conclusions can be drawn:

1. The reduction of voltage caused by reflection phenomena between counterpoise impedance and surge impedance of the lightning stroke is the most important, and next in importance is the induction on the line wire from the wave on the ground wire. The contribution of the counterpoise as far as induction is concerned is negligible.
2. A change in the value of the lightning stroke surge impedance produces changes in insulator voltages to a considerable degree. The small reduction obtained by induction from the counterpoise can therefore be neglected for all practical purposes.

The problem then resolves into calculation of electrostatic induction from the ground wire and the reduction of tower top voltage due to the impedance effect of the ground installation.

During the Pittsfield tests it was found that the surge impedance of an overhead line and of an insulated counterpoise varied with time when an impulse was applied.

In table I are listed the surge impedances of line wire (Z_2) and of insulated counterpoise (Z_3) for different current plane levels. The variation of surge impedances with time found by test is within the range of the values shown in the table and the approxi-

Table I—Induced Voltage and Surge Impedance for Various Depths of Current Plane

h_3	2	8	20	60	120	200	500	1,000
h_2	31	37	49	89	149	229	529	1 029
e_2/e_3	0.007	0.0314	0.0564	0.0948	0.121	0.139	0.171	0.192
Z_2	547	552	561	577	591	604	627	644
t_2 (Test)		0.24	0.41	0.86	2.4			
Z_3	357	397	419	447	465	475	496	511
t_3 (Test)		0.5	0.6	1.03	1.46			
v_2	1	0.992	0.977	0.947	0.924	0.905	0.874	0.851
v_3	1	0.9	0.85	0.8	0.77	0.751	0.723	0.70

mate times of their occurrence are given in the rows t_2 and t_3, respectively.

The conclusion from this is that apparently the current plane starts close to the surface of the earth and then departs from it at a rate of approximately 140 feet per microsecond at the test location. The contention that the current plane starts close to the surface of the earth can also be arrived at by the following considerations:

1. A wave traveling on an overhead wire with approximately the velocity of light enters a counterpoise at that velocity. The velocity in the counterpoise cannot change abruptly from this value. This means that the voltage and current planes must be close together.

2. At the front of the wave, where the current just begins to enter the ground, the "center of gravity of the currents" must be close to the earth's surface, since it takes a definite time for the current to travel into the soil.

The approximate path of the ground plane is shown in figure 1, curve 1, of this discussion for a wave with rectangular front and in curve 2 for a sloped front (by law of superposition). From the tests the line of

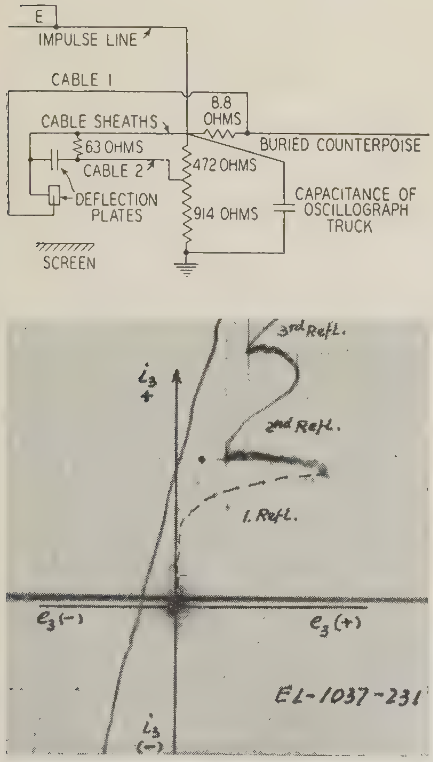


Fig. 2. Method for simultaneous recording of voltage and current in counterpoise and (bottom) oscillogram

penetration actually appears to be straight after the first half microsecond. Up to that time it appears to follow an exponential curve.

The line of penetration (from table 1, t_2 and t_3) is different for the line wire than for the insulated counterpoise, because the wave front in the 2 tests was different, i. e., steeper for the wave on the overhead wire. After the fronts are over the 2 lines are practically parallel. For a rectangular front, the line of penetration would start at zero and parallel to the tail values of the other 2 lines. The rate of penetration will depend upon the resistivity of the soil, the rate being higher for higher resistivity.

Table II—Voltages Across Line Insulators From Stroke to the Tower

Surge Impedance of Stroke	200 Ohms	400 Ohms
Voltage from reflection only	$e_1 = 0.32E$ $e_2 = 0E$ $e_1 - e_2 = 0.32E$	$e_1 = 0.17E$ $e_2 = 0E$ $e_1 - e_2 = 0.17E$
Voltage including 40 per cent induced from ground wire	$e_1 = 0.32E$ $e_2 = 0.13E$ $e_1 - e_2 = 0.19E$	$e_1 = 0.17E$ $e_2 = 0.07E$ $e_1 - e_2 = 0.10E$
Voltage including 40 per cent and 10 per cent induced from ground wire and counterpoise, respectively	$e_1 = 0.32E$ $e_2 = 0.16E$ $e_1 - e_2 = 0.16E$	$e_1 = 0.17E$ $e_2 = 0.09E$ $e_1 - e_2 = 0.08E$
Voltage without counterpoise (Z_e = 154 ohms) using 40 per cent for induced voltage from ground wire	$e_1 = 0.87E$ $e_2 = 0.35E$ $e_1 - e_2 = 0.52E$	$e_1 = 0.56E$ $e_2 = 0.22E$ $e_1 - e_2 = 0.34E$

The depth of penetration for uniform resistivity will depend on the length of the traveling wave or, in other words, on the slope of the tail of the traveling wave. This will explain the difference in induced voltage obtained as shown by part II, figures 11 and 12 of Bewley's paper. The difference between the 2 tests was the traveling wave voltage E and the length of the wave t. In figure 11E = 47 kv and $t \rightarrow \infty$, while in figure 12E = 300 kv and t = 7 micro-

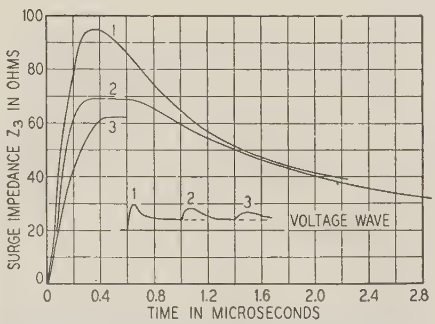


Fig. 3. Variation of surge impedance of 925-foot buried counterpoise for successively applied waves as calculated from oscillogram of Fig. 2

Curve 1 for 1 reflection from impulse generator
Curve 2 for 2 reflections from impulse generator
Curve 3 for 3 reflections from impulse generator

seconds. (Values for traveling waves given here refer to the wave before it reaches the junction between transmission line and counterpoise, while values given in figures 11 and 12 of the paper show voltage after the waves reached the junction.) The difference of 3 per cent in induction can therefore be explained this way since it requires a change in current plane depths of only 10 to 20 feet.

Impedance of Buried Counterpoise

The impedance of a buried counterpoise has been shown to be a function of time. Both papers neglect, however, to show the value of impedance at the front of the waves. This is due to the fact that it is extremely difficult to superimpose 2 oscillograms, taken successively, and find simultaneous values of voltage and current, where fronts of less than 1 microsecond are involved. The only method known to the writer for successfully measuring the fronts is the simultaneous application of current and voltage waves entering the counterpoise on the 2 pairs of deflection plates. This was done in the case of the buried counterpoise and the oscillogram of figure 2 of this discussion was obtained. An analysis of this oscillogram gives the variation of impedance with time as shown in figure 3 for 3 successive reflections from the impulse generator. The values of the second and third reflections are only approximate since the true wave shape was not known and the value of voltage and current of the previous wave at the time when the reflected wave arrives was chosen as zero line. However, the point was to show the similarity of the 3 curves.

The question now is how to arrive at this impedance curve for a counterpoise at any given location. This problem is fairly simple and can be arrived at in the following manner:

The 2 outside values of the impedance function are the surge impedance (initial) and the leakage resistance (final) of the counterpoise. The surge impedance of a buried counterpoise following the reasoning developed in this discussion is a function of time at any point starting with a low value, rising rapidly at first and then slowly as the current plane penetrates into the soil. Simultaneously with the progress of the wave along the counterpoise the leakage

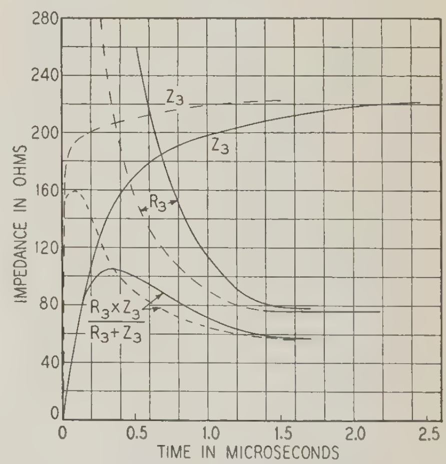


Fig. 4. Calculated transient impedance of 200-foot buried counterpoise

Solid curves for sloped wave front (about 0.4 microsecond)
Dotted curves for rectangular wave front
Z_3 = surge impedance
R_3 = leakage resistance
$\frac{R_3 \cdot Z_3}{R_3 + Z_3}$ = approximate transient impedance

resistance decreases until it reaches its lowest value for steady state conditions (by the process of a great number of small negative reflections). These 2 functions are plotted in figure 4 for a 200-foot counterpoise at the test location. It is an interesting point for speculation that the 2 impedances in parallel give a function approximately equal to that shown in figure 6 of Bewley's paper for

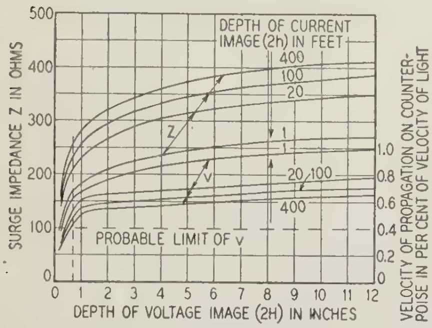


Fig. 5. Relation between surge impedance and velocity of propagation of buried 1/4-inch steel wire counterpoise for different levels of voltage and current images

the tail and figure 3 of this discussion for the front. This sort of procedure is probably permissible as long as the front of the wave has not reached the end of the counterpoise. The dotted curves on figure 4 are plotted for a wave with rectangular front.

The difference in the 2 examples is due to the difference in initial velocity of penetration of current plane into the soil.

Figure 5 of this discussion has been prepared to suggest possible limits for the surge impedance of a buried counterpoise as functions of the depths of voltage and current images. The upper limit of average velocity of propagation can be taken as v_3 = 0.4 of the velocity of light. Now, considering the curves of figure 5, it may be seen that for $v_3 = 0.4$ and $2h_3 = 400$ the surge impedance is approximately 250 ohms. For average soil conditions a value of 200 ohms is more likely. As shown in figure 4 the surge impedance proper is not a constant but rises more or less rapidly depending on the steepness of the wave front.

I propose the following procedure to arrive at the effective value of impedance of a buried counterpoise:

Find value of d-c resistance of a counterpoise by actually burying 200 feet of counterpoise and measuring its leakage resistance. This procedure appears to have merit because this much counterpoise will be available for tower protection and the expense involved is not lost, since at the point of test protection usually is required. Assuming an average velocity of 40 per cent of the velocity of light, it would take $\frac{400}{0.4 \times 985} \cong 1$ microsecond to reduce the impedance of the counterpoise to its leakage resistance, and we assume a surge impedance of 200 ohms. Suppose the leakage resistance by test is 80 ohms. Plotting these 2 points on figure 6 the approximate impedance function for an infinitely steep wave is obtained. To obtain values of maximum impedance when the wave fronts are sloped, straight lines are drawn cutting the line of initial surge impedance at the desired time (i. e., 200 ohms, 5 microseconds, and 200 ohms, 1 microsecond) where these lines cross the line of impedance maximum impedance for that wave front is obtained. Comparing the result with figure 4 it is seen that the values so obtained are pessimistic for the steep wave fronts and in special cases this can be taken care of by actual calculations as in figure 4.

It was found by tests in Pittsfield that the voltage at the entrance of the counterpoise was not subjected to reflections from the end of the counterpoise (see figure 6 of Bewley's paper) when its length was 200 feet. The conductance at the test location was rather low, approximately 0.065 mho per 1,000 feet. Therefore, the only purpose of lengthening the counterpoise would be to decrease its leakage resistance. This can, however, be better obtained by installing a number of 200-foot counterpoises, because the leakage resistance of 4 200-foot counterpoises of approximately 20 ohms is obtained in approximately 1 microsecond, while the same value of leakage resistance with 1 800-foot counterpoise is obtained in approximately 5.5 microseconds. Furthermore, the additional advantage of reducing the initial surge impedance proportional to the number of counterpoises installed is obtained.

The maximum impedance found by figure 6 divided by the number of counterpoises installed should be substituted in the equation $e = E\,\frac{2Z_e}{Z_e + Z}$ as shown previously to obtain maximum tower top voltages. Figure 7 shows the variation with time of the factors affecting counterpoise behavior.

Suggestions for Further Testing

As regards further investigation it is felt that new information and checks should be obtained about the impedance of the counterpoise under different soil conditions, rather than such elaborate tests as recommended by Fortescue and Fielder. The reflection phenomena are well understood and theory has been checked by experiments to prove that reflections can be calculated accurately once the impedances at the junction points are known.

To test the impedance of the counterpoise accurately a measuring circuit such as shown in figure 2 should be used. The impulse generator should be discharged directly into the counterpoise to eliminate complications. For instance, one source of error is repeated reflections.

Fortescue and Fielder show impedance curves for the guy ground and for the counterpoise. The resistance of the guy ground varies from 240 to 50 ohms, while the meggered resistance was found to be 150 ohms. I believe that the values found are not the true values on account of the repeated reflections on the 185 feet of line between the

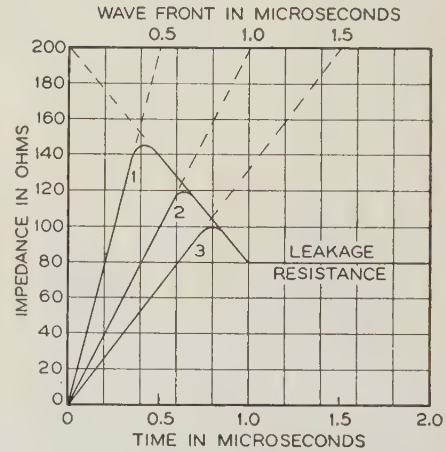


Fig. 6. Transient impedance of 200 foot buried counterpoise

1. Front of applied wave 0.5 microsecond
2. Front of applied wave 1.0 microseconds
3. Front of applied wave 1.5 microseconds

e_2/e_3 = coupling factor
Z_2 = surge impedance of line wire
Z_3 = surge impedance of counterpoise
v_2 = velocity of propagation on line wire
v_3 = velocity of propagation on counterpoise
h_3 = depth of current plane
L_{22} = self-inductance of line wire
L_{33} = self-inductance of counterpoise
L_{23} = mutual inductance
R_3 = leakage resistance of counterpoise
$\frac{R_3 \cdot Z_3}{R_3 + Z_3}$ = effective impedance of counterpoise
P_{22} = constant = $18 \times 10^{11} \times 8.45$
P_{33} = constant = $18 \times 10^{11} \times 1.39$

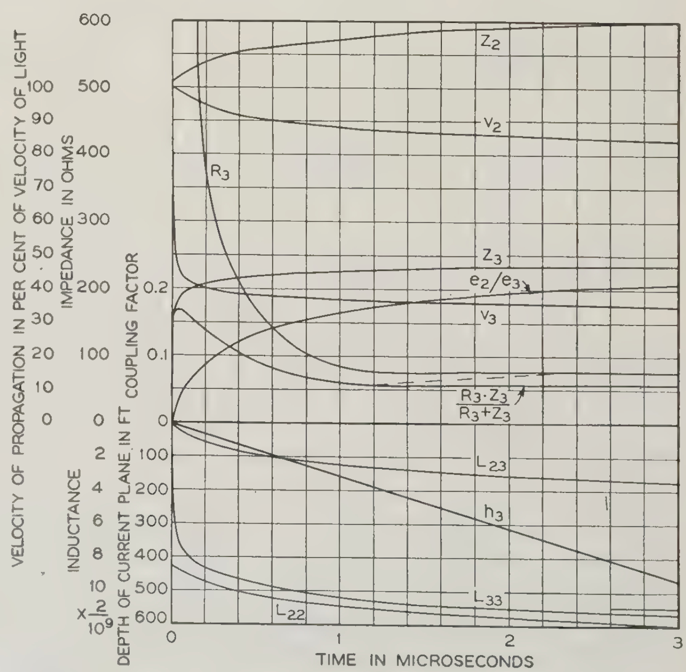


Fig. 7. Variation of coupling factor, surge impedances, velocity of propagation, and depth of current plane with time when rectangular wave is applied on buried counterpoise

impulse generator and the counterpoise or guy ground, respectively. When repeated reflections are applied to the terminal of a variable impedance, such as a counterpoise, the impedance can be found by current and voltage measurements only so long as a reflection from the other end of the line has not returned. To illustrate this point figure 8 has been prepared. This is a replot of figure 2 of this discussion. At time t = 6.5 microseconds, when the reflection from the impulse generator returns, the impedance found by dividing e by i will result in the dotted curve marked "apparent Z," while the impedance without the reflection would have decreased as shown by the solid curve. The difference between apparent and actual impedance will be less than that shown when the length of line is shorter, as in Fortescue and Fielder's figures 5 and 6, but to offset this a greater number of reflections will appear. In figure 5 curve A of the paper at least 3 distinct reflection points can be seen at 0.375, 0.75, and 1.125 microseconds (0.375 microsecond is the time for the wave to travel twice the length of the line). The surge impedance values found for guy wire and counterpoise are therefore distinctly too high at the wave front. In figure 6 of the paper it was shown that the counterpoise impedance reduces to approximately 4 ohms in 5.5 microseconds. The value of the leakage resistance as measured by megger was 6 ohms. The minimum leakage resistance is reached, however, only after the wave reaches the end of the counterpoise and returns. This means in this case that the wave travels at a velocity of $\frac{3,730}{5.5}$ = 680 feet per microsecond, or 69 per cent of the velocity of light. This velocity would be much greater than those obtained by other investigators. However, the reason for this apparent discrepancy in velocity again is the repeated reflections, together with the fact that the inductance of the short piece of the line forms an oscillatory circuit with the impulse generator. A record of a similar behavior can be seen on figure 2 of this discussion, where the beam crosses the i axis well above the zero point, that is the apparent impedance equals zero. Thus the impedances of the guy ground and the counterpoise are too low at 5.5 microseconds.

It therefore appears necessary to avoid connections between generator and counterpoise which give rise to reflections. It is further necessary to have a wave with a very steep front since the impedance varies considerably as the wave front changes (see figure 4 of this discussion).

The contention that the current plane varies with time, as outlined above, and its velocity of penetration into the earth can best be checked by making a test with a long (several thousand feet) insulated counterpoise laid on the surface of the earth. This will eliminate the leakage resistance effect, and show the greatest variation of surge impedance with time. Tests should be made at different locations. Data available to power companies with regard to leakage resistance of installed counterpoises should be collected, so that a picture of how the conductance varies in different localities can be formed.

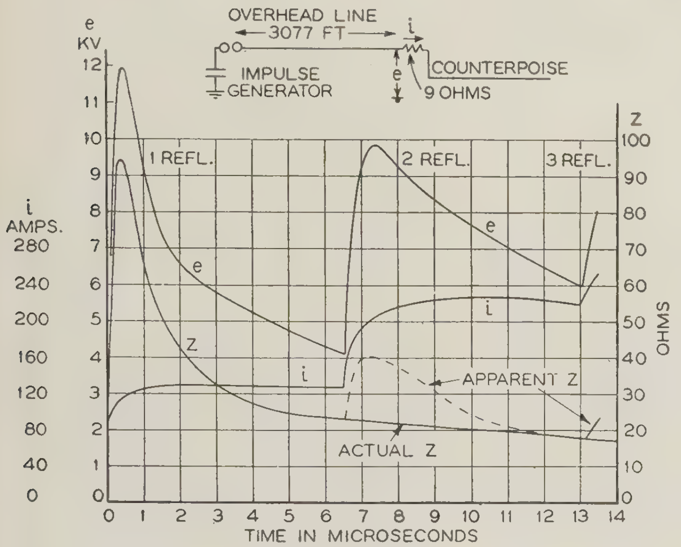


Fig. 8. Errors in surge impedance measurement of counterpoise caused by repeated reflections

S. K. Waldorf (Johns Hopkins University, Baltimore, Md.): The papers of Fortescue and Fielder and of Bewley are comparable in several respects, as they are both based on studies of counterpoises under laboratory conditions. The experimental results of the studies agree very well with each other as may be expected from the soil resistivities of both test localities being very nearly the same.

As Fortescue and Fielder have pointed out, with soil of low resistivity such as they and Bewley encountered in their tests, leakage is the dominating effect in the behavior of the counterpoise. Very frequently soils of much higher resistivity are found in actual installations of counterpoises on transmission lines, often being 25 times as great. Thus, these studies yielding the characteristics of counterpoises buried in soils of moderate resistivity do not establish their effectiveness in soils of high resistivity, as the source of their indicated effectiveness may or may not reside for the most part in the reduction of tower footing resistance which they cause. Fortescue and Fielder state that the question of the usefulness of the counterpoise is still an open one as applied to soils of high resistivity. Bewley's conclusions to his paper lead one to believe that the problem is much nearer to solution.

Bewley states in conclusion 7 of his paper that counterpoises longer than 200 to 300 feet do not appear justifiable. As the experiments indicate that the action of a counterpoise on a surge is as much due to diffusion as any other factor, it seems that in soils of high resistivity, greater lengths than those prescribed are necessary to cause sufficient attenuation for the prevention of an appreciable reflection to the tower. This view is strengthened by the analysis of the lightning oscillogram obtained at Cherry Valley in 1930, given in the paper by Lewis and Foust. That oscillogram indicated a wave front of at least 5 microseconds, and perhaps 10 microseconds, on an actual lightning stroke. In the event of a lightning stroke of this character striking a tower equipped with counterpoises and situated in soil of high resistivity, aside from any coupling effects which may exist, protection due to the counterpoises would rest primarily in the diffusion effect. This would be due to any reflection present returning to the tower long before the wave crest of the stroke had arrived at the tower. Lewis and Foust point out that under such circumstances the effectiveness of counterpoises is measured solely in terms of low leakage resistance. This view neglects any protective effect of coupling that may act under the given conditions, as its presence in appreciable degree has not yet been demonstrated. The lack of conclusive information on the subject has been due to the low soil resistances at the test locations used thus far for counterpoise tests. In any case, to reduce the current density and voltage gradient at the tower footing, a multiplicity of counterpoises in parallel would be more effective than a lesser number of longer length, having the same leakage resistance for the group in both instances.

The installation of a number of counterpoises in parallel introduces the problem of their effective distribution along the right-of-way of a transmission line. They usually cannot be laid in the desirable radial configuration when they are individually more than a few hundred feet long. To confine them within the necessary limits, they must be buried parallel to each other and to the overhead conductors, divided with equal numbers on opposite sides of the tower to which they are connected. It is important to know the practical minimum distance that can be used between parallel counterpoises without the individual counterpoises losing effectiveness due to the proximity of the others in the group. This problem, together with the related one of counterpoise length and number, still requires solution for soils of high resistivity.

Figures 5 and 6 of Bewley's paper show that the transient impedance of a counterpoise falls to its leakage resistance within a few microseconds where the latter is less than the initial surge impedance. A number of leakage resistances have been met on the Safe Harbor-Perryville line of the Pennsylvania Water and Power Co., which are appreciably larger than 150 ohms, the initial surge impedance of a counterpoise found both by Bewley and by Fortescue and Fielder. It would be interesting to see if a surge test of a counterpoise of this type

would show a transient impedance increasing with time instead of decreasing.

The lightning experience summarized by Sporn and Gross, Lewis and Foust, and Bell shows additional evidence that overhead ground wires are essential for protection, and that 2 ground wires are superior to one. The single tripout on the 220-kv line of the Pennsylvania Water and Power Co. listed in table VII of Lewis and Foust's paper occurred on a tower having a tower footing resistance of 25 ohms. The ground resistance of the tower footing alone in this case was 111 ohms and was reduced to 25 ohms by the use of auxiliary grounding consisting of 8 radial wires, each 50 feet long, buried about one foot in the ground, and terminating in salt treated ground rods, each one inch in diameter by 8 feet long. This is in line with the results of Bell's studies indicating that a tower of a 220-kv line is immune to lightning strokes only if its footing resistance is less than 13 ohms.

Observations being made this summer by means of surge crest ammeter links on the 220-kv line, referred to above, are in agreement with the experience cited by Bell and by Lewis and Foust that flashover does not occur unless the product of the tower footing resistance and crest surge current is greater than the maximum permissible surge voltage across the line insulators. These observations, extending over a $2^1/_2$ month period thus far, have involved measurements of lightning currents with 255 links collected from 150 towers and showed surge currents in the line towers ranging from a trace to 45,000 amperes. The maximum value of the product of tower footing resistance and crest surge current has been 1,220 kv. The maximum permissible surge voltage across the insulators on this line is approximately 2,000 kv. It is estimated from these records that the line has been subjected to 66 direct hits by lightning strokes during the observation period without a single insulator flashover or line tripout.

The experience of Sporn and Gross that low tower footing resistance reduces line flashovers, but does not eliminate them, is contrary to that of the other authors. This discrepancy probably is due to the fact that the American Gas and Electric Co.'s experience has been with lines having only single overhead ground wires which do not provide full shielding against direct strokes to the line conductors. Low tower footing resistance is of no help to prevent flashovers due to direct hits on line conductors.

In his description of the counterpoise installed at High Knob, Bell reports that tower footing resistances which formerly varied from 50 to 150 ohms were thus reduced to about 1 to 1.5 ohms. Evidently the former high values are ground leakage resistances as usually measured, whereas the final values are not. It will be of interest to inquire of the author how those latter low values were obtained.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): Lewis and Foust state on page 1184 of their paper that assumptions made in my 1930 paper "Critique on Ground Wire Theory" in regard to the magnitude of lightning voltages and the steepness of the wave fronts are not substantiated by the data presented in their paper. Apparently they placed a wrong interpretation on my "assumptions" (which were not assumptions at all, but estimates calculated from the field data at that time available), and as I shall show, the information contained in the present Lewis and Foust paper substantiates those estimates very well indeed. Specifically, I stated that the maximum lightning voltage was of the order of 10,000 to 20,000 kv (this being the potential of the free traveling wave in the stroke, that is, the incident wave), and in subsequent papers and articles I have shown curves and data based on assumed lightning voltages (the incident wave) of 5,000 to 20,000 kv so as to give the designer a choice in selecting the protective level to which he wished to design. In terms of the surge impedance Z_{11} of the ground wires, the surge impedance Z_0 of the lightning stroke, the tower footing resistance R, and the tower current i, the incident wave of the lightning stroke is (as given in my 1930 paper),

$$e_0 = \left[\frac{(Z_{11} + 2Z_0)R + Z_{11}Z_0}{2Z_{11}}\right] i$$

In 1930 I used a value of $Z_0 = 200$ for the surge impedance of the stroke. Since then I have calculated a set of curves (The Lightning Stroke, *General Electric Review*, Dec. 1933) for this function which I believe to be more exact, and I found that $Z_0 = 400$ is a better average value to use. The surge impedance of a single ground wire is approximately $Z_{11} = 500$, and for 2 in parallel $Z_{11} = 300$.

Table I of the Lewis and Foust paper gives the tower currents and footing resistances for a line having a double ground wire. In this case we have

$$e_0 = \left[\frac{(300 + 2 \times 400)R + 300 \times 400}{2 \times 300}\right] i$$
$$= (1.83 + 200)i$$

and over the section with no ground wire $e_0 = (0.5R + 200)i$

Applying this to their table I we find that

Item No.	e_0	Item No.	e_0
2	4,950	11	8,250
3	5,000	19	5,770
5	5,470	22	8,900
6	4,800	24	6,940
10	4,470	27	6,300

The other records were between 1,000 and 3,000 kv. Thus out of 32 cases we find 2 of the order of 8,500 kv, 2 of the order of 6,500 kv and 6 of the order of 5,000 kv.

Table II of the Lewis and Foust paper applies to a line having a single ground wire. In this case

$$e_0 = \left[\frac{(500 + 2 \times 400)R + 500 \times 400}{2 \times 500}\right] i$$
$$= (1.3R + 200)i$$

Applying this to their table II we find that

Item No.	e_0	Item No.	e_0
1	7,100	26	4,680
3	9,930	28	4,430
18	13,700	29	4,050
10	13,400		

The other records gave from 1,560 to 3,460 kv. Thus out of 23 records we find 2 of the order of 13,500 kv, 1 of the order of 10,000 kv, 1 of the order of 7,000 kv, and 3 of the order of 4,500 kv.

Now it is highly improbable that the most severe possible lightning stroke is included in these records, and consequently it would appear that 20,000 kv (as compared with a maximum of 13,700 calculated from their table II) is not an extravagant estimate for the upper limit of lightning voltages.

With regard to wave fronts the question is not so easily settled. In calculations I have usually taken the steepest wave front of high voltage surges to be one microsecond. Lewis and Foust show fronts in their figure 1 of from 1 to 80 microseconds, with the bulk of them between 3 and 10 microseconds. This line is 65 miles long, of which 37.5 miles are without ground wires, and the oscillograms were taken at one end. Therefore, on an average, the recorded waves must have traveled at least for 19 miles. But we know from impulse tests on transmission lines that the time to crest of a surge increases greatly with the distance traveled. Brune and Eaton (A.I.E.E. Transactions, v. 50, 1931, p. 1132–38) have given cathode ray oscillograms showing that the front of a 700-kv surge may flatten out 10 to 20 microseconds in 14 miles of travel, and about 5 microseconds in one-tenth of that distance. As shown in "Attenuation and Distortion of Waves" (Electrical Engineering, Dec. 1933, p. 876–84) a surge propagates as a multivelocity wave whose components travel at different speeds. *But the fastest wave travels at the velocity of light and is a wave which carries no ground current, so that it preserves the front of the original surge.* This very important fact allows us to estimate the front of the surge at its point of inception, merely by measuring the front of the fast velocity component of the recorded wave. Thus in figure 3*A* of the paper referred to, the total front of the surge after 14 miles of travel is about 20 microseconds, but the clearly defined fast wave component shows a front practically equal to that of the surge at its starting point. Now, of course, if the wave has not traveled far enough for the multivelocity components to disengage to the extent that they are clearly defined on the oscillogram, an estimate of the original front cannot be made by this method. Thus in the figure 3*A* referred to, the multivelocity components cannot be clearly distinguished over the first 1.4 miles of travel. Also, in the case of equal waves on all 3 conductors there will be no fast component. Nevertheless, many of the oscillograms taken on the lines of the Pennsylvania Power and Light Co. distinctly show the multivelocity components, and I suggest that they be reexamined in the light of multivelocity theory. It is unlikely that all lightning wave fronts are as short as one microsecond, or even that any large percentage of them are that short, but there seems to be little doubt that fronts of that order of steepness occur in association with high magnitudes, and therefore if we wish to anticipate the worst conditions we must not ignore these short fronts.

I can sympathize with the wish of Lewis and Foust to solve the lightning problem "merely as a problem of limiting the tower potentials on an ordinary resistance basis, rather than on the basis of dealing with a complexity of traveling wave reflections and couplings." But data now available do not indicate that it is proper to confine the effect of the counterpoise to one of resistance only, or to neglect the reflections from adjacent towers. In the first place it is the reflections from adjacent towers

(where ground wires are used) which fix the shape and duration of the tower voltage as much as does the shape of the lightning wave itself. On a 1,000-foot span and with low footing resistances the insulator flashover can be estimated on the basis of a 5 to 10 microsecond wave. Reflections up and down the tower are of importance for very low footing resistance, high towers, and steep waves. As far as coupling is concerned, it reduces the voltage across the insulators by about 30 per cent. It is interesting to consider a 1.5 × 40-microsecond lightning wave of 10,000 kv impinging on a tower with a 10-unit insulator string, 30 ohms footing resistance, 1,000-foot spans, and a ground wire with 30 per cent coupling.

	Neglecting Reflections and Coupling	Including Reflections and Coupling
Maximum voltage across insulators	1,260 kv	885 kv
Duration	40 μsec	8 μsec
Insulator flashover value	860 kv	1,000 kv

These results show that reflections and coupling are helpful. Incidentally, the conception of a main stroke going up from ground to cloud after an ionized path is created by the initial downward dart, does not essentially alter the picture from a traveling wave point of view (The Lightning Stroke, L. V. Bewley. *General Electric Review*, Dec. 1933).

Lewis and Foust remark on the critical footing resistance of 12 ohms which seems to give immunity to the Wallenpaupak-Siegfried line; Bell, in considering the effects of tower footing resistance, states on page 1193, "it would be very helpful if the secret of why tower footing resistance affects the operation of transmission lines could be made clear"; while Sporn and Gross say, "the magnitude of tower footing resistance required to make a line practically lightning proof has been much discussed, but rarely stated with any assurance; 10 ohms and 5 ohms have been mentioned as possibilities." In an article "How to Design Ground Wires for Direct Stroke Protection" (*Electrical World*, Mar. 17, 1934) there is given a table and formula for computing the tower footing resistance, and it is suggested that the footing resistance be taken as

$$R = \frac{\text{Permissible kv across insulators from table}}{150}$$

Now the Wallenpaupak-Siegfried line has 16-unit insulator strings and 1,000-foot spans. The table gives 1,830 kv for the permissible voltage across the insulators. Therefore, the tower footing resistance should be 12 ohms or less.

The Glenlyn-Roanoke line has 10 insulator units, and I will assume 750-foot spans. The table gives 1,240 kv as the permissible insulator voltage, and therefore the tower footing resistance should be 8.3 ohms or less. Figure 4 of the Sporn and Gross paper indicates that, if their ground wire clearance were adequate, they would get immunity at about 8 ohms. There is no mystery about the effect of tower footing resistance. But footing resistance alone cannot serve as a universal panacea of protection—the length of the span and the ground wire clearance are equal partners with it. Zero footing resistance will not prevent outages if the ground wire clearance is inadequate.

There is, I think, some very conclusive evidence in the Sporn and Gross paper suggesting that they have gone far enough in the matter of reducing the tower footing resistances, and that further benefit will be obtained by *increasing the heights of their ground wires.* According to table VIII of their paper most of the outages occur on the top conductor (vertical configuration), in spite of the fact that the coupling is much closer and therefore the voltage across the insulators less for the top conductor. This means 1 of 2 things: (1) either the ground wires are not high enough to provide sufficient shielding effect, or (2) the ground wires are not high enough to prevent flashovers from occurring out on the span (where tower footing resistance is out of the picture). In either case the remedy is the same—increase the ground wire clearance. On lower and medium voltage circuits, insulator flashover following a steep front stroke to a tower is possible even for zero footing resistance.

Fortescue and Fielder have obtained results from their field tests on a buried counterpoise which agree very well with the results found in tests at Pittsfield and in Michigan. There are, I think, a few improvements which could advantageously be made in their testing technique: (1) place the surge generator far enough away so that reflection from it will not interfere with the events occurring at the test point; (2) use a shorter counterpoise so that the transition from the initial surge impedance to the final leakage resistance is more clearly defined; (3) make tests also on an insulated counterpoise so that the zero plane for current images can be definitely located and the multivelocity components identified; (4) measure velocities by reflections and by the method due to E. J. Wade described in my paper; (5) measure the impedance by the method described in J. H. Hagenguth's discussion and therefrom obtain data on the "front of the wave phenomena."

Fortescue and Fielder apparently adhere to the idea of a "common true ground plane" for both current and voltage images, and proceed to calculate its location by ignoring the fact that this concept is incompatible with the reduced velocities. In the closing discussion to my own paper on the subject I will show calculations based on multivelocity theory (an offspring of taking the current and voltage images at independent depths) which are in detailed quantitative agreement with our oscillograms and establish the validity of the multivelocity theory. The authors state that the coupling was increased by raising the counterpoise 6 feet above ground. This is not substantiated by a comparison of their transcribed oscillograms.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The data from Bell's comprehensive and clear report are of particular interest because of the admirable way in which they have been classified. They present the facts very clearly and the facts completely confirm the general reliability of the theory of ground wire protection against direct strokes which has been developed since the winter of 1929.

In view of the large amount of published data it is hard to see why the author, under the caption "Tower Footing Resistance," page 1193, says, "It would be very helpful if the secret of how much and why footing resistance affects the operation of transmission lines could be made clear." In the case of the effects of tower footing the results are as clear as day. If a line is designed for a certain level of protection it will have a definite number of outages per hundred miles per year which will vary with the number of lightning storms that occur per year. The only factor which may mask the results is imperfect shielding. Imperfect shielding results in a condition in which not all strokes terminate on the ground wires but a percentage terminate on the conductors, so that an imperfectly shielded line has partly the characteristics of an unprotected line and partly those of a protected line. This is well illustrated by reports of lines in the Great Lakes district where 132 kv lines of identical construction over the same territory, but of which some are provided with 2 overhead ground wires and some with only one, show for those protected with 2 ground wires an average of 1.7 outages per hundred miles per year and for the others an average of 5 outages per hundred miles per year. The difference between the 2 is due almost entirely to the imperfect shielding afforded by one ground wire as usually installed in the past. This also accounts for the fact that on many so-called protected lines flashovers take place when the tower footing resistance is low. This is due not to any fault in the theory but to the fact that the lightning stroke which caused the flashover did not terminate on the ground wire but on the line. I have estimated the shielding factor for a 132 kv line with one ground wire as usually installed to be about 70 per cent.

Mr. Bell's figures 2 and 3, pages 1193 and 1194, show quite clearly that with a protected line insulated with 16 standard 10-inch $5^3/_4$-inch spaced insulators no flashovers take place with tower footings below 12 ohms. The value for tower footing resistance which has been set by the writer and his colleagues for a line that is practically lightning proof for the last 5 years is 10 ohms and below. Of course, the effect of higher footing resistances may be offset by using more insulation and *vice versa*, but this requires larger tower structures and is generally much more costly than reducing the tower footing resistance to 10 ohms or less. Inadequate shielding or inadequate insulation cannot be compensated by low footing resistance.

The theory of the protective effect of counterpoises is yet in the development stage, but no doubt it will finally be brought to a satisfactory solution. In the meantime many more counterpoises are being installed in various parts of the country and this will increase the amount of data available for determining the effect of counterpoises. It is gratifying to note that the $2^1/_4$ mile line over High Knob provided with a single parallel counterpoise still has a perfect record.

Among the 220 kv lines that have been designed according to the theory discussed

above, is the Philadelphia portion of the Roseland-Plymouth Meeting connection which has a perfect record up to date, according to my information. The Safe Harbor line has had one outage since it went into operation in January 1933. This line passes through a difficult terrain where great trouble had been experienced in keeping down the tower footing resistance.

It is interesting to note, in the paper by Sporn and Gross, a decided improvement in performance resulting from the installation of counterpoises. Their data on the performance of 132 kv lines protected by 2 overhead ground wires of conventional design is at variance with all other statistical data that I am familiar with. In the Great Lakes district where careful statistical records have been kept for years the reduction for 2 ground wires as compared with 1 is 66 per cent whereas Sporn and Gross indicate only 20 per cent. It seems to the writer that this discrepancy is statistical data needs some explanation. Certainly none can cavil at the performance of the Windsor-Canton line which seems to be consistent except for the year 1926.

W. A. Hillebrand (University of California, Berkeley): Mr. Sporn's problem is the improvement of transmission line reliability, for which the starting point must be the careful compilation of records such as those reported upon in the paper by Mr. Gross and himself.

In the solution of this problem insulation plays an important rôle, for which reason it is significant that, in going from the 132-kv circuits reported by Sporn and Gross to the 220 kv circuits of which the records are given by Lewis and Foust, an increase in insulator length from 10 to approximately 18 units or about an 80 per cent increase in impulse flashover voltage resulted in a decrease in tripouts per 100 circuit miles per year from the order of 11 to about 2.5, or over 75 per cent.

In view of the exceptional reliability and freedom from outage of some highly insulated wood lines, the unfavorable record of the 60.3 circuit miles of such construction reported by Sporn prompts inquiry as to structural details of the line in question. Are crossarms steel or wood? Are the poles protected by grounding wire against lightning? Are guys insulated?

Do the records of 2-circuit lines indicate the relative frequency with which lightning will cause both circuits to flash over? In their discussion of 2-circuit outages Messrs. Sporn and Gross infer that in most cases the second circuit tripped out because operated in parallel at the time of the fault. Is this believed to be generally the case?

Records presented in both papers of maximum value of tower current due to a lightning stroke and of stroke polarities are confirmed by the most comprehensive field investigations of lightning yet reported upon. The investigation covers the records obtained in Germany during the summer of 1933 from 10,000 surge crest ammeters of the type referred to by Messrs. Lewis and Foust, which were installed on transmission lines of various voltages. One 60 kilometer, 100-kv line had every tower and the ground wire at every tower equipped with the magnetic recording links. The data were published in the *Elektrotechnische Zeitschrift* for May 24 and 31 of this year, which arrived in this country after the papers under discussion had been submitted for publication (Die Messung von Bligzstromstärken an Blitzableitern und Freileitungsmasten, von Dr.-Ing. H. Grünewald. May 24, 1934, page 505, and May 31, 1934, page 536).

Lighting Performance of 132 Kv Lines

Discussion and authors' closure of a paper by Philip Sporn and I. W. Gross published in the August 1934 issue, pages 1188–94, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

W. H. Burleson and **M. M. Kenneally** (both of Ohio Brass Co., Mansfield): The paper by Sporn and Gross is of unusual interest in that it includes an elaborate tabulation of operating and design statistics regarding the 132 kv system of the American Gas and Electric Company. This information is contained in table III, pages 1196–7 of the August 1934 issue of ELECTRICAL ENGINEERING. The industry as a whole, and the Institute in particular, can be greatly benefited by such contributions. We of the manufacturing group welcome such information and hope that the authors will continue their past performance of publishing interesting operating information. We believe that an exchange of information of this kind is of great importance to operating, designing, and development engineers. Too frequently investigations and design are predicated on assumptions which if data is collected and made public, can be far more accurate and reassuring than assumptions made purely upon the perception or skill of the individual engineer.

The utility of such tabular information as contributed by Sporn and Gross can well be illustrated by an additional analysis that we have made predicated upon the operating and design information contained in the paper. Since the early 1920's designing and operating engineers have attempted to evaluate the expected rate on arc protecting and shielding devices in connection with high voltage transmission lines. Information upon which to base such study has been highly local in color and limited as to mileage or years of experience. The method of collecting data on the individual properties made difficult the comparison of operating results. We believe that the 31 lines studied by the authors, in a system extending from Chicago to eastern Virginia, crossing the states of Illinois, Michigan, Ohio, West Virginia, and Virginia, are sufficient at least to attempt to evaluate the return that may be expected from investment in arc protecting and shielding devices of at least 3 designs. Many engineers have expressed the belief that on lines so constructed the expected lightning outages do not exceed 10 per 100 right-of-way miles per annum, and by employing modern high speed relaying and breaker operation, little or no serious damage to conductors and insulators from power arcs will be experienced. Such engineers, therefore, have raised the question of how much can be expended for arc protection on such lines.

We have taken the liberty of taking operating and physical data from the data submitted by the authors in table III, and regrouping the lines so as to include in a single tabulation:

1. Lines having arc protection consisting of a ring at the lower end of the string and a horn at the upper end of the string.
2. Lines having arc protection consisting of rings at the lower and upper ends of the string.
3. Lines having no arc protection devices. In order to afford additional measure of the value of arc protection devices, we are assuming that if these lines had been equipped with arc protection consisting of rings at the top and bottom of the string, all damage indicated in the authors' table would have been avoided, or 100 per cent efficiency is assumed in the arc protecting devices.

While the mileage and number of lines that were available for this comparison are not as extensive as in other groups, the amount of damage occurring on such lines is much more positive than from the lines equipped with rather elaborate arc protecting devices.

In table I we have summarized this information. While the assumptions as to the probable damage resulting from power arcs are subject to some question, we believe the evaluation of such damage will on the average be sufficient. For instance, conductor damage may vary from very casual repairs of from \$2.00 to \$3.00 to smooth rough spots on the conductor to the replacement of 2 or 3 spans of conductor in inaccessible locations. The latter may cost several hundred dollars. However, it is assumed that all repairs can be made on prearranged interruptions and work performed under favorable conditions.

It will be noted by the estimate submitted that individual lines have earned a fair return on the investment whereas other individual lines and the total of any of the groups indicate an exceedingly small return on the invested capital.

From a study of the above data it would appear that the following conclusions may be drawn:

1. Where the expected outages resulting from insulator flashovers exceed 10 per hundred miles of line per year some form of arc protection may be highly desirable.
2. The amount of money that may be expended for arc protection may be warranted as the expected number of insulator flashovers increases.
3. Where the voltage distribution on the string is sufficient to produce corona on the units of maximum stress, a part of the investment expended for arc protection may properly be charged to insulator shielding.
4. Where the size of the conductor and/or the combination of size and expected current in the arc are sufficient to produce burndown of conductor or insulator string, the return from investment in arc protecting devices will be much greater and therefore a larger initial investment is warranted.
5. Each transmission project can well be individually considered in determining the advisability of arc protection.
6. Careful consideration should be given in determining whether or not to spend available funds in reducing the number of expected flashovers by

(*a*) Lowering the tower footing resistance

(*b*) Improving the type, kind, and placement of overhead ground wires

(*c*) Lowering the height of the conductor above ground

(*d*) Reducing the span length

(*e*) Using expulsion gaps to prevent the flow of power current

(*f*) Improving the relay protection

(g) Increasing the speed of breaker operation
(h) Maintenance of breakers and relay system.

This is only representative and illustrative of the use to which that information as contributed by the authors can be put by both operating engineers and manufacturing engineers interested in and charged with the production of materials to be used on modern high voltage transmission lines.

Philip Sporn and **I. W. Gross** (both of the American Gas and Electric Co., New York, N. Y.): It has been pointed out by Bewley, Waldorf, and Fortescue that the reason why flashovers have occurred at the typical towers on our 132-kv system, where the tower footing ground resistance is low, is due to a lightning stroke contacting the line wires; that is, due to the incomplete shielding provided by one ground wire as used. This seems a very plausible explanation on the basis of the direct stroke theory and traveling wave phenomena on the line. We have considered this point in our analysis, but fail to find conclusive proof that flashing over of towers with low footing resistance is due to this cause. For example, if the lightning stroke contacted the line in midspan and produced a flashover there, or between that point and the tower, it would be expected, in a few cases at least, that evidence of burning of the line wires due either to the lightning current or the subsequent power arc would be found. In only one case that we recall in the past few years has such an occurrence been reported. As practically all our 132-kv lines receive a tower climbing inspection once each year and the line conductors between towers are very carefully inspected at this time, it would be expected that if such flashovers did take place some evidence of this would be observed. We are therefore rather reluctant to accept this explanation as the reason why towers of low footing resistance have flashed over. While we are thoroughly sympathetic with the theory of lightning discharges to a transmission line and the consequent voltages built up, we are, nevertheless, inclined to place considerable reliance in the record of line performance as obtained.

In reference to Mr. Hillebrand's comments on wood pole lines, the single line on which we reported has steel crossarms, has no ground wire, but does have a down conductor tying the steel crossarm to a coiled wire at the base of the wood pole structure. During the past 2 years, this line has been operated with this ground wire having a gap of about 8 feet between the lower crossarm and the ground. There are a number of all-metal guy wires on this line; guy insulators are not used. It was not intended in presenting and discussing the performance of this line to indicate that it was typical of present trends in wood pole construction, and we do not believe that too much weight should be placed on a direct comparison of relative performance of this wood pole line and the steel tower lines on our system.

Regarding the matter of 2-circuit outages referred to by Mr. Hillebrand, we believe these do indicate the relative frequency with which lightning causes both circuits to flash over. In other words, the load on the system in all cases is such that if one of the 2-circuit lines trips out from any cause, the other line will carry the load without tripping from overload. It is therefore apparent that when 2-circuit interruptions occur during lightning storms, these are due to practically simultaneous lightning faults on both circuits. While, of course, it is not known that some of these 2-circuit outages are not due to lightning faulting one circuit and the power arc spreading into the second circuit before the faulted circuit is interrupted, it is believed that this type of occurrence is extremely rare in the case of our 132-kv lines.

The discussion of Kenneally and Burleson on the economics of grading ring and shield protection is a typical example of how easy it is to prepare a set of figures that may be totally misleading. Thus, the data as presented in the summary are formidable enough, but so many errors of assumption were made in the preparation of them that no extended discussion of the results presented is warranted. As typical of some of the many errors, the discussers assume that conductor damage may vary from casual repairs of $2.00 to $3.00 for minor burns up to several hundred dollars, but no repair, no matter how minor (that is, one that involves as a minimum the burning of a single strand) can be made properly without lowering the conductor and this on a long span transmission line is quite an elaborate procedure, and will mean, in general, from a half a day to a day's work of a line gang. The sums involved in that, therefore, would be in the order of from $40.00 to $50.00, and not from $2.00 to $3.00.

Table I—Summary of Economic Analysis of Arc Protection, American Gas & Electric Company's 132 Kv System

	Total Ring and Ring Protected Lines	Total Ring and Horn Protected Lines	Total Protected Lines	Total Lines Without Arc Protection	Total A. G. and E 132 Kv System
Physical Data					
Length of Line, Right of Way Miles	587.2	671.9	1,259.1	160.9	1,420
Voltage Rating of Construction, Kv	132	132	132	132	132
Minimum Operating Voltage, Kv	33	132	33	132	33
Maximum Operating Voltage, Kv	132	132	132	132	132
Operating Data					
Lightning Tripouts, 1932 (No.)	58	87	145	10	155
Lightning Tripouts, 1933 (No.)	71	96	167	13	180
Lightning Tripouts, 1932 and 1933 (No.)	129	183	312	23	335
Insulator Damage, 1932 (No. Cases)	19	38	57	14	71
Insulator Damage, 1933 (No. Cases)	11	24	35	9	44
Insulator Damage, 1932 and 1933 (No. Cases)	30	62	92	23	115
Conductor Damage, 1932 (No. Cases)	14	32	46	14	60
Conductor Damage, 1933 (No. Cases)	11	19	30	5	35
Conductor Damage, 1932 and 1933 (No. Cases)	25	51	76	19	95
Ring Damage, 1932 (No. Cases)	82	99	181	..	181
Ring Damage, 1933 (No. Cases)	41	69	110	..	110
Ring Damage, 1932 and 1933 (No. Cases)	123	168	291	..	291
Total Damage, 1932 and 1933 (No. Cases)	134	223	357	28	385
Economics of Arc Protection*					
Effectiveness as Insulator Protection (Per Cent)	77	72	74	100*	74
Effectiveness as Conductor Protection (Per Cent)	80	74	78	100*	78
Arc Protection Devices Installed (No.)	14,215	14,567	28,782	4,823*	28,782
Installed Cost[1] (Est. Dollars/Set)	7	5	..	7*	..
Total Investment (Dollars)	99,454	72,835	172,289	32,961*	172,289
Carrying Charges on Arc Protection[2] (Dollars/-Annum)	14,910	10,926	25,836	4,944*	25,836
Cost of Protection 1932 and 1933 (Dollars)	27,154	20,072	47,226	9,592*	47,226
Max. Protection to Insulators[3] (No. Cases)	104	161	265	23*	265
Max. Protection to Conductors[4] (No. Cases)	108	172	280	19*	280
Value of Insulators Protected (Dollars)	2,122	3,210	5,332	468*	5,332
Estimated Cost of Insulator Damage Avoided by Protection[6] (Dollars)	1,872	2,880	4,752	414*	4,752
Estimated Cost of Conductor Damage Avoided by Protection[7] (Dollars)	5,400	8,600	14,000	950*	14,000
Estimated Total Cost of Damage Avoided by Protection (Dollars)	7,272	11,480	18,752	1,362*	18,752
Ratio of Estimated Cost of Protection to Probable Damage Without Protection[8]	3.8:1	1.75:1	2.5:1	7 1*	2.5:1

* For comparison, lines without arc protection have been assumed equipped with ring and ring protection. The estimated damage assumes 100 per cent protection of both the insulator and the conductor. These items have not been included in the system total column.
1. Installed cost of ring and ring—$7.00 per set in place. Installed cost of ring and horn—$5.00 per set in place. No allowances made for extra cost yoke string protection.
2. Annual carrying charges, including interest, depreciation, and taxes, assumed 15 per cent.
3. Number of cases rings protected insulators.
4. Number of cases rings protected conductor.
5. Value of insulators protected at $2.00 per unit.
6. Assumes all cases protected (3) would have incurred a damage of 3 units and rings not been used. Damaged units valued at $2.00 per Unit, plus $4.00 per Unit labor charge; Total $6.00 per Unit.
7. Assumes all cases protected (4) would have incurred damage if rings had not been used. Average conductor damage estimated $50.00 per Case.
8. Ratio of carrying charges on protection to maximum expected damage had protection not been used.

Again the authors state that it is assumed that all repairs can be made on prearranged interruptions and that work will be performed under favorable conditions, but it must be recalled that many of the lines in question are single circuit, which means there is no such thing as a favorable time for interrupting the service of the line. In fact, to get one of the lines out of service frequently may mean preparations lasting days to get old or uneconomic plants properly manned and on the line, and even then the service would be subjected to a considerable hazard. The fact of the matter is that conductor burning is one of the few things that cannot be tolerated in the operation of an important line, if the entire investment (not alone the investment in a very minor item like a ring assembly) is not to be nullified by its unreliability.

The discussers again are in error in assuming a cost of $6.00 to change an insulator on a smashed insulator string. For work carried out in quantity, the figure might be reasonable, but for sporadic and spasmodic repairs the actual cost is more likely to be 4 or 5 times that. Again, in figuring cost of investment, the authors assume a necessary return of 15 per cent. This would be excellent if it could be obtained, but it isn't obtainable today to utilities in general on the entire plant investment, and there is no reason why such a cost figure has to be assumed in carrying insulator protective equipment.

Another item of expense the discussers failed to consider is the more frequent line inspection required on a line not equipped with arcing protection, if any attempt is to be made to keep the line conductors and insulators in a condition even approximately that existing on the protected line.

The above are only some of the many errors of omission and commission that render valueless the elaborate tabulation presented.

The remaining conclusions of the discussers, such as that the amount of money that is warranted for arcing protection increases as the expected number of flashovers increases, or that each transmission project should be discussed individually, are of course too axiomatic to need any further comment.

Theory and Tests of the Counterpoise

Discussion and author's closure of a paper by L. V. Bewley published in the August 1934 issue, page 1163–72, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): This paper is particularly interesting to me because it reports a series of tests similar to those made at Trafford by Mr. Fielder and myself, and similar troubles and disappointments were encountered on account of the low resistivity of the soil on the site of the test. In addition to these troubles, however, in making our tests we had the elements to contend with because our tests were made during the months of January, February, and March, and the winter in Pittsburgh was unusually severe.

In general the tests reported in this paper lead to the same conclusion as those reported in our paper. Neither set of tests will enable the engineer contemplating a future transmission line or considering improving an existing line to determine whether it is more economical to use counterpoises or to reduce the tower footing resistances by other means, such as driven grounds. In other words, to obtain a logical answer he will be compelled to make some kind of comparative tests, for which he probably is not properly equipped, or else use his judgment based on the experience of those who have used counterpoises (of which there is very little statistical data at the present time) and wait for years to have his judgment confirmed or contradicted.

How much better it would be if similar tests to these could be made jointly by all interested utilities to determine the behavior of counterpoises in representative locations. I feel sure that the problem could be solved satisfactorily by half a dozen such tests carried out on sites having different soil conditions. The state of California offers exceptional opportunities as it presents a great variety of soil conditions. Transmission lines are no doubt available and in process of construction where such tests could be made covering a large variety of soil conditions at very little expense. The first tests on system stability were made in California and, as a result, the solution of an important problem of system design was achieved. The lightning problem is just as important from the system design standpoint as the stability problem, indeed it is an important element in the general problem of system stability as lightning proof lines will enable transmission lines to be loaded close to their static stability rating. For long transmission distances it is hard to contemplate a line over some portion of which counterpoises will not be needed.

Bewley brings in his artificial lightning surge over a short length of line (3,077 feet), a method which is to be highly recommended. For a section of experimental line which does not extend in 2 directions from the point of attachment of the surging line the effect should be equivalent to a surge impedance of the lightning channel of about 250 ohms. At Trafford we would have liked to do the same but space limitation prohibited it. The method of obtaining the velocity of propagation in the buried counterpoises is extremely interesting and the results obtained are about what would be expected. There never has been any doubt in my mind that the velocity of propagation of the main surge in the counterpoise is relatively slow as compared to that in the line and our tests indicate that the velocity in the line is considerably less than the speed of light. The effect of both leakance and the high dielectric constant of the earth is to slow up the velocity of propagation.

On one point I do not agree with the author. In figure 11, part II, he shows the same surge potential for e_1 and e_3, although e_1 applies to the overhead line and e_3 to the buried counterpoise. Again in figure 12 he shows similar results. The 2 surges in question are so much alike that one is forced to the conclusion that they are identical and the assumption has been made that e_1 and e_3 have the same value. Repeated tests have been made by us which demonstrate that such an assumption is not valid. In our tests at Trafford we found differences of potential due to the down drop lead from line to counterpoise of appreciable magnitude. In fact, in making measurements of surge impedance of grounds and counterpoise we found it necessary to place our measuring terminal right at the counterpoise because even a short length of line (about 70) between the counterpoise gave incorrect results.

L. V. Bewley (General Electric Co., Pittsfield, Mass.): Hagenguth's thorough analysis of our test data has resulted, I think, in 2 outstanding contributions to our knowledge of counterpoise behavior; first with respect to front of the wave phenomena, and second with respect to the simplification of counterpoise calculations. I will discuss these 2 aspects of the problem briefly.

Front of the Wave Phenomena

In this and 2 previous papers ("Attenuation and Distortion of Waves," L. V. Bewley, Electrical Engineering, December 1933, page 876–84. "The Counterpoise," L. V. Bewley, *General Electric Review*, February 1934) it was shown that the earth current must penetrate at a rapid rate immediately following the passage of the wave front, and then at a more gradual rate. After the "readjustment transient" at the wave front the effective current depth may be considered as constant as far as induction on the conductors is concerned, because the inductance coefficients change very little with an increase of current depth. From this consideration of the character of the earth current transient, several important effects could easily be explained in a qualitative way, but Hagenguth, from his careful and detailed study, has obtained actual quantitative data on the subject. In our original tests separate oscillograms of voltage and current were taken, and from them the surge impedance computed as a function of time by taking the instantaneous ratios of e/i. In the case of the overhead wires and the insulated counterpoise the impedance function as thus computed appeared to start at a high initial value, quickly fall to a minimum value, and then slowly increase. The explanation for this behavior was given in figure 13 of my paper. However, in the case of the buried counterpoise it was not at all clear whether the impedance started at a high value, fell to a minimum, and then slowly increased; or started at a low value, rose abruptly in a short interval, and then continued slowly to rise. Either interpretation could be arrived at by a very slight mismatching of the fronts of the voltage and current waves. Hagenguth therefore suggested that oscillograms be taken with voltage and current, respectively, on the 2 plates of the oscillograph. When this was done there was no doubt that the impedance of the buried counterpoise starts at a very low value and then rapidly rises to its path of relatively slow increase.

This is not inconsistent with the explanation for the insulated counterpoise given in figure 13 of my paper. In the case of the insulated counterpoise 1 foot above the surface of the earth, the earth current could get no closer than within 1 foot of the counterpoise, and therefore the minimum inductance was comparatively large, so that the change of capacitance exerted a dominating effect at the wave front. With the buried counterpoise the earth current is initially very close to the conductor, the inductance is practically nil, and consequently the surge impedance starts at nearly zero. The great influence of the initial inductance on the shape of the impedance curve is illustrated in figure 1 of this discussion.

The penetration of the current into the earth changes the inductance, and in consequence changes the surge impedance, velocity of propagation, and coupling. It appears permissible to ignore the change of capacitance in the case of the buried counterpoise. We may then summarize the effect of the current penetration in table I of this discussion.

From these considerations it is easy to visualize the flattening of the wave front, lengthening of the wave tail, decreased coupling of a short wave, etc. Hagenguth in his discussion has given curves and tables for the effect of the current penetration. He has also suggested that the reduced coupling in figure 12 of the paper, as compared with that in figure 11, is no doubt due to the smaller depth of current penetration associated with the shorter wave of the higher voltage surge to which figure 12 applies. It appears, therefore, that in regard to the front of the wave phenomena, we know a great deal more in a quantitative way than heretofore.

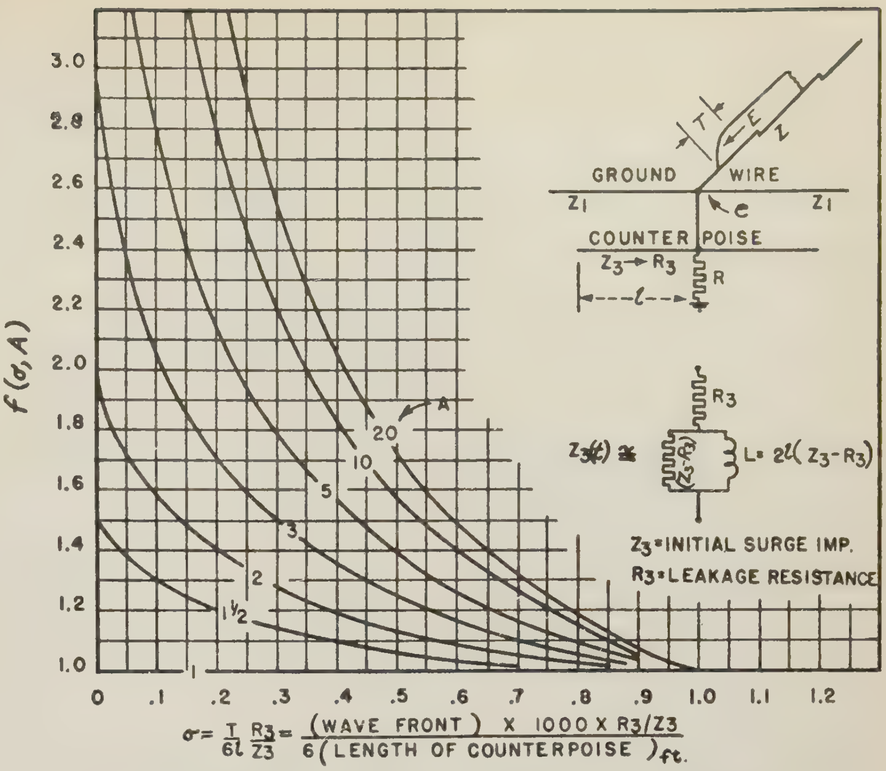


Fig. 2. Lightning voltage at top of tower permitted by a counterpoise

$$e = \frac{2E}{1 + Z/r'}\left[1 + A\left(\frac{1-\sigma}{A\sigma - 1}\right)\epsilon^{-3t/T}\left(\frac{A-1}{A\sigma-1}\right)\epsilon^{-A\sigma 3t/T}\right]$$

$$e_{\max.} = \frac{2E}{1 + Z/r'}\cdot f(\sigma, A)$$

$$A = (1 + Z/r')/(1 + Z/r)$$

$$1/r = (N/Z_3 + 1/R + 2/Z_1)$$

$$1/r' = (N/R_3 + 1/R + 2/Z_1)$$

T = Front of incident lightning wave
N = Number of counterpoise wires

Simplified Counterpoise Calculations

From our own theory and tests, as well as tests made in Michigan in 1930 and tests by Fortescue and Fielder, 3 facts stand out rather clearly:

1. The additional coupling effect on the line wires due to a counterpoise is rather small in comparison with that of the ground wire. We found not more than 4 per cent while Fortescue and Fielder show from 4 to 8 per cent, and theory suggests that it will not exceed 10 per cent.

2. The initial surge impedance obtained by extrapolating the impedance curve to zero time appears to be of the order of from 100 to 250 ohms, with an average value of 150 ohms. The Michigan tests gave 220 ohms, the Pittsfield tests from 120 to 160 ohms, and the Trafford tests 150 ohms.

3. The impedance falls in a roughly exponential fashion from its initial surge impedance value to its final leakage resistance (which may be somewhat less than the measured d-c resistance). The time of transition requires approximately one complete reflection on the counterpoise, and since the velocity on the counterpoise is close to $1/3$ the velocity of light, this means that the transition requires $t = \frac{6}{1{,}000}$ (length of counterpoise in feet).

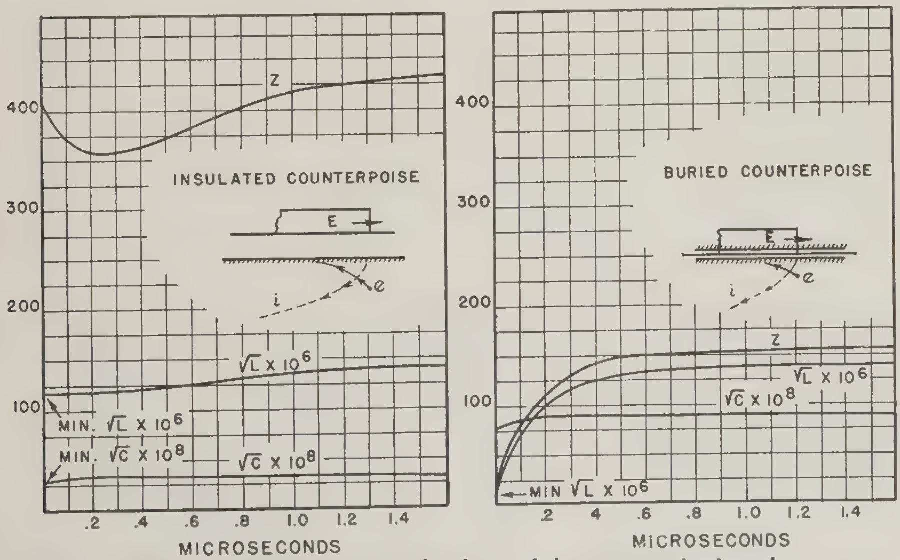


Fig. 1. Effect of initial inductance on the shape of the counterpoise impedance curve

Hagenguth suggests in his discussion that the additional coupling due to the counterpoise be ignored entirely and that simplified calculations be based on regarding the counterpoise as an impedance varying from an initial value Z_3 to a final value R_3 in time $t = 6l$. He has calculated the impedance curve by considering half that portion of R_3 uncovered by the advancing wave front to be in parallel with the instantaneous Z_3.

In this connection I propose an equivalent circuit for the counterpoise consisting of its leakage resistance R_3 in series with $(Z_3 - R_3)$ shunted by an inductance L such that the time constant of the circuit is essentially the same as that of the actual counterpoise. On this basis a complete set of estimating curves may be obtained as shown in figure 2 of this discussion, so that for any assumed or measured values of the voltage of the lightning surge, the surge impedances of the stroke, ground wire, and counterpoise (initial), and the tower footing and counterpoise resistances, the corresponding voltage on the ground wire may be readily found. These curves are computed from the equivalent circuit of the counterpoise, choosing L so that the time constant of the equivalent circuit matches that of the actual transient im-

Table I—Effect of Current Penetration

Penetration of Current	Effect on Inductance	Effect on Surge Impedance	Effect on Velocity	Effect on Coupling
Initially close to surface of counterpoise	A minimum, and very small	A minimum, and practically zero	High, and practically the velocity of light	A minimum and very small
Initial downward displacement	Rapidly increases	Rapidly increases	Rapidly decreases	Rapidly increases
Relatively slow downward trend	Slowly increases	Slowly increases	Slowly decreases	Little change
Returns upward to wave tail	Slowly decreases	Slowly decreases	Slowly increases	Slowly decreases

pedance where a unit function current is applied. It is not imperative that the exact value of Z_3 be known, since the results are not greatly affected by a departure from an average value of $Z_3 = 150$, but the leakage resistance R_3 must be known from field measurements, either with direct current or a bridge.

As an example of the application of these curves, take:

Z = 400 ohms surge impedance of lightning stroke
Z_1 = 500 ohms surge impedance of ground wire
Z_3 = 150 ohms surge impedance of counterpoise
R_3 = 40 ohms leakage resistance of counterpoise
l = 200-foot length of counterpoise
N = 2 counterpoises per tower
R = 200 ohms tower footing resistance
T = 1 microsecond wave front
E = 10,000-kv lightning stroke voltage (incident wave)

$$1/r = (N/Z_3 + 1/R + 2/Z_1) = (2/150 + 1/200 + 2/500) = 0.0223$$

$$1/r' = (N/R_3 + 1/R + 2/Z_1) = (2/40 + 1/200 + 2/500) = 0.0590$$

$$A = \frac{1 + Z/r'}{1 + Z/r} = \frac{1 + 400 \times 0.0590}{1 + 400 \times 0.0223} = 2.5$$

$$\sigma = \frac{R_3}{Z_3}\frac{T}{6l} = \frac{40}{150}\,\frac{1 \times 1{,}000}{6 \times 200} = 0.22$$

Therefore, the maximum voltage on the ground wire is

$$e_{max} = \frac{2E}{1 + Z/r'} f(\sigma, A) = \frac{20{,}000}{24.6} \times 1.55 = 1{,}260 \text{ kv}$$

Allowing 30 per cent coupling between ground wire and line wire and 5 per cent additional coupling due to the counterpoise, the voltage across the insulators would be:

$$1{,}260(1 - 0.35) = 820 \text{ kv.}$$

Multiple Counterpoise Wires

Since it has been shown that the additional coupling due to the counterpoise is of secondary importance as compared with its impedance effect, it is at once apparent that a given length of wire is more efficiently employed as a number of radial counterpoises than as one continuous wire. Figure 3 of this discussion shows 1,000 feet of wire having a final leakage resistance of 10 ohms and an initial surge impedance of 150 ohms per wire. If this is used as a single long counterpoise the impedance decreases from 150 ohms to 10 ohms in about 10 microseconds. If, however, the 1,000 feet is used as 2 500-foot counterpoises, the impedance starts at 75 ohms and reaches 10 ohms in about 5 microseconds. Further subdivision reduces the initial impedance and shortens the time of transition, both highly beneficial effects. However, it is evident that a region of diminishing returns is approached by 4 wires, and this is accentuated by the fact that for very short wires the end effects become pronounced, reflections are not wiped out, mutual inductance between wires plays a more important part and, most important of all, the leakage resistance may exceed the surge impedance for very short wires. *The proper length of each counterpoise wire should be such that its leakage resistance is substantially less than its surge impedance, but otherwise its length in thousands of feet need not exceed $^1/_6$ the shortest front in microseconds of any lightning surge to which it may be subjected.* This criterion ensures that the full length of the counterpoise will have been reduced to substantially its leakage resistance by the time the shortest front wave has reached its crest, and that the voltage will not exceed that permitted by the surge impedance only. If a longer counterpoise is used its minimum resistance will not be available for the shortest front waves, although the additional length would prove beneficial for longer fronts, but not so much so as is obtainable by using more of the shorter wires. These considerations suggest that the standard counterpoise length should be from 200 to 300 feet (if this is sufficient to reduce the leakage resistance below 150 ohms) and that as many wires be used as necessary to secure the desired reduction in voltage as given by the curves of figure 2 of this di cussion.

Waldorf points out in his discussion that in many actual installations a length of from 200 to 300 feet is not sufficient to reduce the final leakage resistance below the surge impedance, and he inquires as to the maximum number of counterpoise wires which may be used in parallel before the mutual surge impedance between wires becomes excessive. He also asks what shape the transient surge impedance curve has when the leakage resistance is higher than the surge impedance.

In accordance with the above criterion, if from 200 to 300 feet are not sufficient to

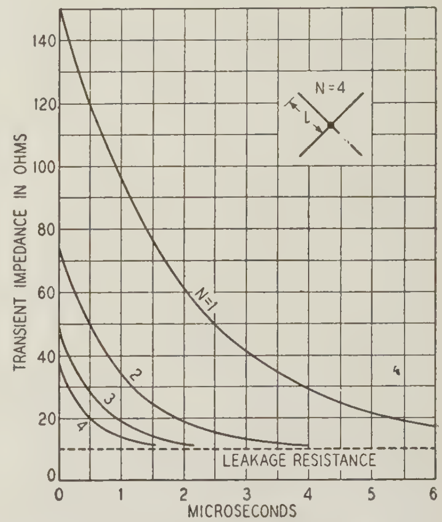


Fig. 3. Effect of the number of wires on the counterpoise impedance

reduce the leakage resistance below the surge impedance, say 150 ohms, then longer lengths should be used, and this will usually mean continuous tower-to-tower counterpoise wires. If the leakage resistance exceeds the surge impedance, then the transient impedance initially decreases, reaching a minimum approximately in time $t = 6l/1{,}000$, then increasing and reaching a maximum equal to the leakage resistance.

An exact determination of the mutual surge impedances between radial counterpoise wires is rather awkward, but at least 8 wires may be used without much of a boost in surge impedance. If the wires are run parallel along the right of way, a minimum spacing of 10 feet appears permissible.

Fortescue suggests that additional field tests be carried out in soils of different characteristics. While these tests would be very desirable as confirmation of the existing data and theory, yet I do not at all believe that such tests are necessary before a rational counterpoise analysis can be made. Since my paper was written, Hagenguth has made a careful analysis of our records and reported his findings in his discussion of this paper; and I have extended my calculations in this discussion

Table II

Waves leaving starting point	$f_1(v_1)$	$f_2(v_2)$	$f_3(v_3)$
Time of arrival at transition point	l/v_1	l/v_2	l/v_3
Reflections of velocity (v_1)	$_1f_1'(v_1)$	$_2f_1'(v_1)$	$_3f_1'(v_1)$
Time of arrival at starting point	$2l/v_1$	$l/v_2 + l/v_1$	$l/v_3 + l/v_1$
Reflections of velocity (v_2)	$_1f_2'(v_2)$	$_2f_2'(v_2)$	$_3f_2'(v_2)$
Time of arrival at starting point	$l/v_1 + l/v_2$	$2l/v_2$	$l/v_3 + l/v_2$
Reflections of velocity (v_3)	$_1f_3'(v_3)$	$_2f_3'(v_3)$	$_3f_3'(v_3)$
Time of arrival at starting point	$l/v_1 + l/v_3$	$l/v_2 + l/v_3$	$2l/v_3$

to include successive reflections into the second and third generations. The agreement with test results is so good in all respects that I no longer have any doubt that our theory is sufficient and adequate for making routine design calculations once the leakage resistance is known, and this can be measured quite easily.

Fortescue calls attention to the fact that I used the same oscillogram for the ground wire surge and the counterpoise surge in part III, figures 11 and 12 of my paper. The height of our pole was only 30 feet and as our wave front was about 0.4 microsecond we could observe no difference. Furthermore, it must not be thought that connecting the oscillograph to the overhead wire by a separate down lead gives any truer reproduction of the surge on the overhead wire than does connection to the tie between the ground wire and counterpoise as used in my tests because there are successive reflections in both cases.

Calculation of Successive Reflections

In connection with figure 4 of my paper it was pointed out that the reflections obviously showed the characteristics of multivelocity components, and in the text the initial multivelocity wave components were calculated. Since the paper was written the calculations have been extended to include the reflections, and the numerical agreement with the oscillograms in all details has been found to be excellent. The complete calculations are entirely too long to be reproduced here, but a brief résumé and summary of the results seem desirable, since, as far as I know, this constitutes the first evidence of the exact quantitative agreement obtainable by multivelocity theory, and should therefore put at rest those intimations raised during the discussions of my first paper (Attenuation and Distortion of Waves, L. V. Bewley, Electrical Engineering, December 1933, and the discussions at the 1934 winter convention published in the March and April 1934 issues, page 471–3 and 595–8) on multi-velocity theory to the effect that the mathematics was not a true description of the phenomenon.

The insulated counterpoise used in our field tests was 925 feet long, and at its far end was grounded through driven pipes having a ground resistance of 240 ohms. When the surge is applied at the starting end of the counterpoise, multivelocity waves of 3 velocities (100 per cent, 98 per cent, and 84 per cent of the velocity of light) move out on the ground wire, line wire, and counterpoise. These waves arrive at the transition point (grounded end of the counterpoise) at different times, and as each wave arrives it generates reflected waves of all 3 velocities. Thus 9 individual waves start back toward the origin, leaving the transition point at different instants in 3 separate groups, each group consisting of 3 separate wave velocities. See table II of this discussion.

In view of the fact that v_1 and v_2 are so nearly equal we can greatly simplify the work by dealing with only 3 wave groups with respect to their time of arrival at the starting point:

Group *A*: $({}_1f_1' - {}_1f_2' - {}_2f_1' - {}_2f_2')$ returning approximately at $(2l/v_1 \cong 2l/v_2)$
Group *B*: $({}_1f_3' - {}_3f_1' - {}_2f_3' - {}_3f_2')$ returning approximately at $(l/v_1 + l/v_3)$
Group *C*: $({}_3f_3')$ returning at $(2l/v_3)$.

The transition point equations applying at the grounded end (resistance R) of the counterpoise are

$$e_1 + e_1' = e_1''$$
$$e_2 + e_2' = e_2''$$
$$e_3 + e_3' = R(i_3 + i_3')$$
$$i_1 + i_1' = i_1''$$
$$i_2 + i_2' = i_2''$$

Substituting the multivelocity components, these 5 simultaneous equations are then solved for the reflections. Corresponding to the 3 conditions I, II, and III of figure 4 of my paper, the numerical values are as given in table III of this discussion.

Table III

Reflected Wave	Group	Condition I	Condition II	Condition III
${}_1f_1'(v_1)$	A	$0.0145\ E_0$	0	$0.0135\ E_0$
${}_2f_1'(v_1)$	A	0	0	0
${}_3f_1'(v_1)$	B	0	0	0
${}_1f_2'(v_2)$	A	0	0	0
${}_2f_2'(v_2)$	A	$-0.0020\ E_0$	$0.0009\ E_0$	$-0.0010\ E_0$
${}_3f_2'(v_2)$	B	$0.0113\ E_0$	$0.0440\ E_0$	$0.0526\ E_0$
${}_1f_3'(v_3)$	B	0	0	0
${}_2f_3'(v_3)$	B	$0.0112\ E_0$	$-0.0051\ E_0$	$0.0057\ E_0$
${}_3f_3'(v_3)$	C	$-0.0206\ E_0$	$-0.0805\ E_0$	$-0.0964\ E_0$

Now regarding these reflections as incident waves impinging on the transition conditions at the starting point of the counterpoise, and assuming all components of any group to arrive there simultaneously, new transition point equations can be written for each condition. These equations are given in table IV of this discussion.

Table IV

Condition I	Condition II	Condition III
$e_1 + e_1' = e_1''$	$i_1 + i_1' = 0$	$e_1 + e_1' = e_1''$
$i_1 + i_1' = e_1''/Z_1$	$i_2 + i_2' = 0$	$e_3 + e_3' = e_1''$
$i_2 + i_2' = 0$	$i_3 + i_3' = e_1''/Z_1$	$i_2 + i_2' = 0$
$i_3 + i_3' = 0$	$e_3 + e_3' = e_1''$	$i_1 + i_1'' + i_3 + i_3' = e_1''/Z$

Substituting multivelocity components and solving these simultaneous equations for each condition, there finally results:

Condition	Reflection Group	Voltages Due to Reflections on Ground Wire	Line Wire	Counterpoise
I	A	$-0.0031\ E_0$	$-0.0205\ E_0$	$0.0007\ E_0$
	B	$0.0225\ E_0$	$0.0397\ E_0$	$0.0574\ E_0$
	C	$-0.0207\ E_0$	$-0.0363\ E_0$	$-0.1211\ E_0$
II	A	0	0	0
	B	$0.0783\ E_0$	$0.0783\ E_0$	$-0.0347\ E_0$
	C	$-0.1479\ E_0$	$-0.1479\ E_0$	$-0.2740\ E_0$
III	A	$0.0076\ E_0$	$-0.0328\ E_0$	$0.0076\ E_0$
	B	$0.0329\ E_0$	$0.0989\ E_0$	$0.0330\ E_0$
	C	$-0.2846\ E_0$	$-0.2010\ E_0$	$-0.2833\ E_0$

The contribution of these reflection groups is easily identified on the oscillograms of figure 4 of my paper. For example, consider the voltage e_2 on the line wire under condition II:

e_2 Condition II	Calculated	Test
Original Wave	0.064	0.068
+ Groups *A* and *B*	0.142	0.136
+ Group *C*	−0.006	0.00

All points on these oscillograms check very well with the above calculations, within the limits of accuracy of this kind of work. It has, therefore, been shown that the multivelocity theory of traveling waves gives correct quantitative results.

Lightning Investigation on Transmission Lines—IV

Discussion of a paper by W. W. Lewis and C. M. Foust published in the August 1934 issue, page 1180–6, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue (Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): Lewis and Foust have reached the conclusion that the tower top potential is given by the product of tower footing resistance and crest current. We are asked to believe that no matter how severe the stroke may be, it will cause no flashover on a poorly insulated line protected with ground wires if the tower footing resistance is very low, of the order of 1 or 2 ohms. Yet in our laboratory work using artificial lightning surges on actual transmission lines, we have observed potentials of considerable value in 30 or 40 feet of down drop leads to ground. A large tower has, of course, a much lower surge imped-

ance than a single wire, but, on the other hand, it may be 2 or 3 times as high. We estimate, therefore, that where tower footing resistances are below 10 ohms potentials of the order of 1,000 kv reaching crest value at one microsecond and dropping off very quickly may be expected from very severe strokes, due to the reflections in the tower alone. As a rough criterion to determine the likelihood of flashover for varying values of tower footing resistance, the method may have some value especially when the footing resistances are above 50 ohms.

To obtain a perspective of lightning potentials that occur on 100 miles of line by a single cathode ray oscillograph station located at one point of the line would require probably 100 years, and even then the vagaries of lightning storm paths might vitiate the results. To obtain an idea of the severity of lightning strokes that may hit a transmission line the first requisite is an unprotected line which cannot be flashed over by lightning and the second is unlimited time and a large number of observation stations. Quite contrary to the experience implied in the third paragraph of the first column on page 1184, calculations of protection level which we have made show a close correspondence with statistical data obtained on transmission lines new and old. It is possible that heights of ground wire indicated by the theory are on the safe side although the writer feels that it is too early to reach a conclusion. In the Safe Harbor line the ground wire is 30 feet at its maximum separation above the line wire. In the Philadelphia end of the Roseland-Plymouth Meeting interconnection the ground wire according to my recollection is about 22 feet at its maximum spacing above the line wires. The record of the Safe Harbor line up to the time that the authors released their paper is given in table VII as 0.7 outage per 100 miles per year; up to date there have been no further outages on this line although this year's lightning has been exceptionally severe. The Philadelphia end of the Roseland-Plymouth Meeting interconnection according to my information has a perfect record up to date. Another recently installed line that was designed and built according to direct stroke theory is the 132-kv circuit around Indianapolis. Great pains were taken during its installation to keep the tower footing resistance to a low value in the neighborhood of 10 ohms. That these measures were justified the record of this line during the 3 or 4 years of its operation completely bears out. Since 1929 the writer has set the value of 10 ohms tower footing resistance as the limiting value if good lightning performance was desired, provided there are properly placed ground wires. This value was obtained as the result of calculations carried out in accordance with the direct stroke theory bringing in the effect of tower reflections. In particular it has been stated that a design with properly placed and spaced ground wires and with 16 standard insulators would result in a practically lightning-proof line. This has had remarkable confirmation in the statistical data reported in this paper.

The data obtained with the surge crest ammeter is very interesting but further study and records will be required before it can be decided that 100,000 amperes maximum in the stroke for a surge impedance of 200 ohms for the channel is too high for a very severe stroke. When it is remembered that for an isoceraunic level of 30 the frequency of occurrence of strokes of this severity is probably of the order of once per 100 miles every 3 years, the likelihood of obtaining a record on the crest ammeter is not very great.

As regards the mechanism of the lightning stroke a flood of light was thrown on this phenomenon by the investigations recently reported by Dr. Schonland of South Africa. I understand that Dr. Schonland's results have been duplicated at Pittsfield within the past year. I do not agree with the authors' interpretation of Dr. Schonland's photographs. I can find no evidence or theoretical basis for the assumption that the receding highly illuminated channel is due to the stroke proceeding from earth to cloud. It is true that it has this appearance but appearances are often misleading. One obvious reason for discarding the theory put forward is that apparently the illuminated channel which moves toward the cloud does frequently stop so to speak in midair. What then becomes of the surge which is alleged to start from the earth? In my paper entitled "Lightning Discharges and Line Protective Measures" (A.I.E.E. TRANSACTIONS, volume 50, 1931, page 1090–1100) I gave for the first time an explanation of the cloud discharge which seems to agree with Dr. Schonland's test, and later on in my paper before the International Electrical Congress I gave the same explanation in more detail. I gave the speed of movement of the initial streamer in the first paper as less than $^1/_{20}$ the velocity of light, and in the second paper I gave its velocity as being greater than 4.3×10^7 centimeters per second. According to the theory presented in these papers the initial streamer progressed very slowly ($^1/_{20}$ velocity of light) so that the energy of its channel was mostly potential energy. When the streamer reached earth or a highly conducting body, such as a transmission line, this potential energy was instantly changed into $^1/_2$ kinetic and $^1/_2$ potential energy so that a large current began to flow in the channel. The potential energy which can be considered as a standing wave would be instantly changed into 2 traveling waves of equal value and sign, one of which moves down the channel and the other up the channel. Where these 2 waves overlap there is very little current in the surge and the energy is practically all potential energy, but as the negatively traveling wave recedes toward the cloud $^1/_2$ of the potential energy in the channel is released in the form of current which is indicated by the intense illumination of the portion of the channel in which the current flows, giving the appearance of a discharge moving up the channel from earth at $^1/_{10}$ the velocity of light. In other words, the current is due to the component wave moving down the channel and not to the component receding wave. The energy of the surge moving down the channel is at first derived from the initial streamer which leaves the channel ionized and highly charged. It may finally extend into the cloud and derive its energy directly.

While the oscillogram, figure 5, is of great interest as one of the highest surges recorded on a steel tower line, it does not appear to me to justify all the conclusions arrived at by the authors nor do I think that the surge recorder evidence is very conclusive since the leads to the recorder are under the influence of the field of the tower and the recorders may not register the true difference of potential across the 40 feet of tower. The fact that the statistical data presented by the authors, together with other data of the same kind that has been published in the past, apparently bears out the protection levels obtained by taking into account the reflections in the tower, seems to me to be very convincing evidence of the substantial correctness of the theory.

Counterpoise Tests at Trafford

Authors' closure of a paper published in the July 1934 issue, page 1116–23, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

C. L. Fortescue and **F. D. Fielder** (both of Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.): The only point concerning the testing technique that has been raised in this discussion is that of Mr. Hagenguth who has questioned the accuracy of the surge impedance measurements.

The first claim is that the line length between the generator and the entrance to the counterpoise gives rise to oscillations which reduce the value of the results. It is by no means apparent how oscillations can affect the results since the voltage measurement at the counterpoise connection gives the voltage to ground at every instant, while the drop across the increasing resistance gives the current entering the counterpoise at corresponding times. If the applied wave has oscillations both of these measurements are affected, and the oscillations are taken into account. In any case the magnitude of the oscillations is small compared to that of the main waves, as shown by the voltage oscillograms, and, therefore, they can have little effect on the results. Mr. Hagenguth has attempted to show that the oscillations occur at intervals of 0.375 microsecond, and are due to the 185-foot length of line, since this time represents the time for a reflection along this length. The line diagram shows this cannot be true, since there is an additional 100 feet of line back to the surge generator terminal. The resulting period would be at least 0.55 microsecond, which interval is not regularly defined on oscillograms.

The contention is also made that the minimum values are too low, since the minimum values of surge impedance should equal the measured megger resistance (a-c, not d-c). For the test of the guy ground the megger value was 150 ohms, and the surge impedance around 50 ohms after several microseconds. There is no discrepancy because of the short distance down to the true ground plane. The high voltage used for the surge tests and the resulting corona formation could easily lower the surge impedance to a value much less than the steady state value as measured with low voltages. Nor is the argument of the velocity of propagation along the counterpoise valid, because when there is such a

short distance between true ground plane and the counterpoise and when the earth resistivity is low in value, the effect of the distant part of the counterpoise is negligible. The measured effects are approximately the same whether the counterpoise is 200 feet or 1,000 feet in length.

Finally, it is not reasonable that the surge impedance of a counterpoise or guy should be low at the beginning of a surge, and then increase in value, as indicated in the discussion.

At the first instant there is little difference between a counterpoise and a line in air, since the leakage effect has not started. With the progress of time, however, the leakage effect becomes greater, and the impedance, therefore, decreases.

Mr. Hagenguth recommends a surge generator location directly at the counterpoise terminal for the measurement of surge impedance. Such a procedure, however, places the surge generator ground altogether too close to the counterpoise, and leads to false results. Rather it is to be recommended that the surge generator and counterpoise be separated to eliminate reduce this end effect.

Lightning Investigation on a 220 Kv System

Author's closure of a paper published in the August 1934 issue, page 1188–94, and presented for oral discussion at the lightning session of the Pacific Coast convention, Salt Lake City, Utah, September 5, 1934.

Edgar Bell (Pennsylvania Power and Light Co., Hazleton): Professor Waldorf's inquiry of counterpoise resistance measurements can be answered as follows: The practice of the Pennsylvania Power and Light Co. in measuring tower footing resistances is to use a megger ground tester and take sufficient trial measurements that the probable true value of resistance is obtained as recommended by the manufacturer. Normally the current and potential probes are located along the right of way. After the counterpoise was installed over the High Knob section of the Wallenpaupack-Siegfried line it was not feasible to do this, and measurements were made along directions approximately at right angles to to the direction of line (and counterpoise). This necessitated dragging the test leads and probes into the adjacent woods, but time and care were taken to insure that the measurements were accurate.

After the counterpoise was installed, measurements were made under 2 conditions; (1) with counterpoise disconnected and pulled a few feet away from the footings of the tower under test and (2) with counterpoise connected and in final position. Measurements under condition (1) gave values ranging from 2.1 to 3.0 ohms; those under condition (2) were less, ranging from 1.0 to 1.6 ohms.

Mr. Fortescue expresses surprise because I suggest that there is still some mystery to the effect of tower footing resistance in preventing flashovers on transmission lines having overhead ground wires. There is no mystery to the theory proposed; this seems to be essentially correct and the Wallenpaupack-Siegfried data serve to confirm the theory. My point was that published results do not always agree with theory, as Mr. Fortescue admits, although with an explanation that in such cases shielding is "imperfect."

The remaining lines of the Pennsylvania-New Jersey 220-kv Interconnection (Conowingo-Plymouth No. 1 and No. 3, Plymouth Siegfried and Roseland-Plymouth) have suffered 30 tripouts due to lightning. The locations of 13 of the faults are unknown. Of the remaining 17 faults, 10 were caused by flashovers at towers of less than 13 ohms resistance. In 8 cases the resistances ranged from 3 to 7 ohms. These lines are of more recent construction that the Wallenpaupack-Siegfried and ground wires have been more advantageously placed and greater clearances maintained. Because of facts like these, I cannot agree that the results are yet as clear as day.

Data published on measured structure currents due to lightning, and the possible error which can reasonably be assumed to apply to these measurements are as yet quite meager. When we have a reasonable number of representative measurements of structure currents and correlating information as to shielding, footing resistance, flashover, and similar essential data, then the problem of tower footing resistance will be much clearer, probably sufficiently so for all practical purposes.

Simplified Measurements of Sound Absorption

Discussion and authors' closure of a paper by Arthur L. Albert and Tom B. Wagner published in the August 1934 issue, page 1160–2, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

R. B. Bonney (Mountain States Telephone and Telegraph Co., Denver, Colo.): Since these measurement deal with sounds of varying frequencies over a wide range, it occurs to me that they should be made with this in view. I should like to ask if it is not necessary, in making the measurements, to carry on a considerable number of tests over a wide range of frequencies in order to get accurate results.

E. W. Templin (Electrical Research Products, Inc., Los Angeles, Calif.): It is pointed out in this article that sound absorption coefficients obtained by the tube reflected wave method and by the reverberation chamber method may not agree due to a difference in panel vibration under the 2 conditions. Another factor is present which may, over the measurable frequency range, introduce discrepancies greater than those due to panel resonance.

In the tube, the sound impinges against the material at normal incidence, whereas in the reverberation chamber it impinges against the material at random incidence. Consequently, it may be expected that the difference in coefficients obtained by these 2 methods will vary with the porosity and roughness of the surface of the material being measured.

Another point worthy of mention is that in adjusting the length of the tube to obtain standing waves at any frequency, the optimum length of the tube is a function not only of the frequency but also of the material under test. This is because for materials which absorb sound the apparent end of the tube is not at the surface of the material due to the phase angle introduced when the reflection takes place. It is necessary to adjust the tube length carefully for each particular material being tested so that a maximum intensity is obtained at the plane of the sound source at each frequency.

Our experience indicates that due to the highly irregular frequency characteristic of loudspeakers, slight variations in their performance with use may noticeably change their output efficiency at certain frequencies. For this reason, more accurate and more consistent measurements of absorption may be made if the microphone is so mounted that it can explore the tube and pick up the maximum and minimum positions at each frequency. The coefficient of absorption will then be obtained from the difference in intensity at these 2 positions rather than from a single absolute measurement. It can be seen that coefficients obtained by the former method are independent of minor changes in the sound source output.

Comparative measurements have indicated that in general for wallboard materials having a comparatively smooth finish of low sound absorption, the tube method gives results in close agreement with those obtained with the same material rigidly mounted in a reverberation chamber. However, for materials which provide greater absorption due chiefly to rough, porous, or perforated surfaces, the discrepancy between measurements made by the 2 methods may be quite large. For such materials the reverberation chamber method more nearly approximates the conditions under which the material is used in rooms or auditoriums and, therefore, the coefficients so obtained are the more reliable.

A. L. Albert (Oregon State College, Corvallis) and **T. B. Wagner:** As Mr. Bonney brings out in his question, sound absorption measurements should be made over a wide range of frequencies if reliable data are to be provided. In our studies, tests were made at frequencies from 256 to 4,096 cycles per second. For sake of brevity curves for this entire range were not included in the paper.

Mr. Templin points out that it is probable that the manner in which the sound waves impinge against the absorbing test specimen with the tube method is somewhat different from the random incidence of the reverberation chamber. It should be mentioned, however, that with the inverted cone radiator of the moving-coil loud speaker that was used, and with the cone close to the test specimen, the wave pattern was very complex.

We note with interest that others have found that the actual "image" plane of an absorbing material may not be the actual

surface of the material, and that it is necessary to adjust for this image reflecting surface rather than for a dimensional fraction of the wave length. In our tests, this actual maximum reflecting point was carefully located.

It is probable that, as Mr. Templin mentions, more accurate and consistent measurements can be made if several wave lengths are included and the microphone used to explore the values of several maximum and minimum points. We were interested in making the tests as simple as possible consistent with engineering reliability, and for this reason the method described in our paper was adopted. Subsequent tests have proved our system to be satisfactory for most engineering work.

Mr. Templin discloses interesting information in stating that comparative measurements indicate that for smooth surfaces of low absorbing qualities the tube method and the reverberation chamber method agree, but that for materials of high absorbing properties they do not agree so closely. In this, we presume that Mr. Templin refers to coefficients calculated from data taken by the tube method. Since in our tests the coefficients were not calculated, but were obtained by direct comparison with materials standardized by the reverberation chamber method, these discrepancies should be materially reduced.

Electrical Figures on Plates in Air

Discussion and author's closure of a paper by J. Gibson Pleasants published in the February 1934 issue, page 300–07, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

W. A. Hillebrand (University of California, Berkeley): That an insulated body, which may be either a conductor or an insulator, can acquire and retain an electrostatic charge is, historically, one of the earliest facts learned in the study of electricity, although its practical implications seem to be but little appreciated. An example of the practical importance of surface charge, aside from the use of condensers, is found in the "corona disappearance" voltage of high tension insulators. As the voltage applied to an insulator is raised a corona discharge will take place when the appropriate potential is reached. If the voltage is raised above this point and then reduced, corona will disappear at a voltage lower than that at which it appears on increasing voltage. The cause is unquestionably to be found in the positive space charge which collected on the glazed surface during the positive half wave while above the corona point and which, when the electrode becomes negative, increases the voltage gradient about it and causes air breakdown at a lower applied voltage.

Although the veins and boundary of the Lichtenberg figure mark the electron tracks, they are actually due to the repulsion between gas ions that have charged the sulphur or other dust used. Accordingly they show not only electron track but residual charge and therefore their sharpness of definition is largely determined by the amount of absorbed moisture, particularly if the dust is applied after the discharge has taken place.

Dr. Pleasants' explanation of the difference in rate of growth of positive and negative figures as due to the angle at which the electrons, with rod negative, impinge upon the glass plate is not convincing to me. As indicated by the author himself, the difference in the rate of growth of the 2 figures would seem to be completely accounted for by the positive surface charge which, when the rod is positive, in effect extends the electrode and the radius of ionizing potential, whereas its effect is to reduce it when the rod is negative.

The subject treated by Dr. Pleasants is important, the Lichtenberg figure offers a valuable means of studying it, and the contribution of the paper to our knowledge is welcome.

J. Gibson Pleasants (California Institute of Technology, Pasadena): Mr. Hillebrand's discussion of the "corona disappearance" voltage on insulators, that is, on the disappearance of the corona at a lower voltage than that at which it appeared, is very interesting as another example of the family of hysteresis effects so well known in connection with both magnetic and electrostatic systems.

I should like to comment particularly on the paragraph of Mr. Hillebrand's discussion beginning with the sentence, "Although the veins and boundary of the Lichtenberg figure mark the electron tracks, they are actually due to the repulsion between gas ions that have charged the sulphur or other dust used." Let us recall that the veins appear only in the positive figures. The negative figure is composed of a very great number of very fine, strictly radial lines, practically equal in intensity and spacing, as is to be expected with the moving particles repelled from the center. In recording the figures, the dust was applied a few seconds after the occurrence of the surge, when no more gas ions were present as such, but only the surface charge on the plate. There was no movement of the dust as it settled on the plate; it simply adhered to that portion of the plate which carried a charge, and avoided the portion that did not. The veins in my positive figures simply indicated canals which were free of charge, due to the neutralization of the positive surface charge by the flow of electrons back to the electrode through these channels. The light veins in positive figures obtained on photographic plates are no doubt due (1) to the action of photons given off during the recombination going on in these channels of flow of the electrons, and (2) perhaps also to direct action of the electrons themselves on the plate.

Mr. Hillebrand is surely justified in finding my explanation of the difference in rate of growth of the 2 figures (as being due to the angle of motion of the electrons with respect to the glass) not very convincing. It is offered only as a suggestion, and is not altogether satisfactory to me, although, even after a review of many opinions on the subject, I can come upon no other picture of the situation which suits me as well.

Just as my theory admitted but one moving particle, i. e., the negative one, Mr. Hillebrand's theory seems to admit of but one kind of surface charge, the positive one. Now, actually, a very heavy negative surface charge remained on the plate after the formation of the negative figure, as evidenced by the adherence of the red lead to it (the dust was a mixture of red lead and sulphur, the former taking on a positive charge, the latter a negative, when shaken together), just as the adherence of the sulphur after the positive surge proved the existence of a positive surface charge. It is possible that as the concentric, negative "wave" of electrons expands around the electrode during the negative surge, a surface charge of positives is left behind, due to the lower mobility of the positive ions and this would introduce another difference in the conditions between the formations of figures of the 2 polarities in addition to the direction of motion of the electrons. No trace of this inner, positive surface charge is found afterward, however, when the figure is registered with dust.

Together with Mr. Hillebrand, I should welcome more exact data, and a sounder analysis of the course of this intricate and interesting phenomenon.

Insulator Arcover in Air

Discussion and author's closure of a paper by F. W. Maxstadt published in the July 1934 issue, page 1062–8, and presented for oral discussion at the selected subjects session of the Pacific Coast convention, Salt Lake City, Utah, September 7, 1934.

W. A. Hillebrand (University of California, Berkeley): Whenever an insulator or insulating material is used we have 3 regions to consider, the dielectric itself, the surrounding material which must be another dielectric, and the surface boundary between the 2. The properties of the bounding surface are often more important than those of the 2 dielectrics. It is this surface, which is extremely difficult to define in the first place, whose properties Dr. Maxstadt has studied so successfully.

The author's analysis of the mechanism of surface breakdown as given on page 1065 is, I believe, correct.

Also, the results given in tables I and II, showing an almost twofold increase in breakdown strength of bakelite and glass rods by properly corrugating the surface, cannot fail to interest any one concerned with the use of insulation because they establish the limit of improvement obtainable under ideal conditions.

In paragraph 4 of his introduction the author says: "If transmission line voltages are to be pushed to considerably higher magnitudes than at present, some advantage no doubt will have to be taken of the greater arcover strength obtained by providing a uniform field in the neighborhood of the insulator." This statement overlooks the fact that the potential gradient over the suspension insulator is as good as or better than that in free air between conductor and crossarm. Any shield that increases insulator arcover must also cover the conductor

for such a distance on either side that dimensions become prohibitive and clearances to towers are reduced. It is difficult to see how any material improvement can be expected from such a device.

The errors inherent in the conventional air density correction of arcover values have long been recognized but with no clear understanding as to how they can be eliminated. It is occasionally necessary to compare flashover values from different laboratories, which demands correction of some sort for the effect of air density so that I cannot agree with the author's contention on page 1065 that such a correction should not be made.

On page 1067 is the statement that "in dry arcover different shaped insulators, exclusive of apparatus bushings, having the same arcing distance, have roughly the same arcover strength." This is true only up to the point where the unit section length has been so extended that general cascading takes place.

G. M. Barrow (Westinghouse Elec. and Mfg. Co., Derry, Pa.): From the viewpoint of commercial engineering and production of insulators, satisfactory explanation of the phenomena of flashover is still lacking as the author suggests. In many respects, however, the problem of insulator arcover in commercial testing is becoming simplified by improvements in methods of test and determination and use of correction factors for the several variables affecting it.

The physical picture depicted of arcover at normal frequency is logical. The suggestion that higher impulse breakdown is due to the time consumed in evaporation, however, does not agree with the accepted theory of the relation between ionization and time lag and both the normal frequency and impulse arcovers respond similarly to corresponding changes in humidity.

Literature of the Institute reviews comprehensive tests which definitely establish that the flashover value of commercial insulators varies on the order of 2 per cent per grain over the normal range of absolute humidity.

The effect of flanges in offsetting the effects of humidity are not proved conclusively, I believe, by the data in tables I and II on the flashover of bakelite and glass rods having 260 threads per inch. It would be very interesting to compare similar data on rods without the threaded surface under identical conditions of test. It is suggested also that the results of such a test be reported on the basis of absolute rather than relative humidity.

Referring to the data on the bakelite rod, and disregarding the values where the arc struck along the sample, the data show an average value of 151.5 kv at an average of 31 per cent relative humidity and 160.5 kv at a relative humidity of 95 per cent. This performance indicates that changes in humidity did have an effect on the flashover of the bakelite rod. This is a variation of 6 per cent and is greater than would normally be considered satisfactory after applying the usual corrections in commercial testing.

The author probably will agree that for practical intents and purposes the use of a linear relation for air density correction over the atmospheric range from 0.850 to 1.10 will introduce very little error. Relative to insulation for the higher transmission voltages, the improvement that can be obtained with closely spaced flanges is covered in Torok and Archibald's paper on "Diameter and Spacing of Suspension Insulators" presented at the Milwaukee meeting in 1932.

The paper does not give any data or explanatory discussion of the author's reference in the last sentence of the paper to the influence of geometrical details of the insulator on impulse flashover.

J. C. Rah (Joseph C. Rah and Co., Chicago, Ill.): There are several important points brought out in this paper, one of which is the author's mention of the discrepancies that occur in measurements of flashover voltages by various observers. There is no question that the measurements should be more standardized and that the technique of measurement should be adapted so as to eliminate such wide discrepancies upon which theories sometimes are built that are confusing rather than illuminating. A definite step toward uniformity therefore would be very welcome.

Under the subheading "Surface Effects" in the first paragraph, the author says that all the difficulties are eliminated because of a simple testing apparatus. I do not believe that this is exactly correct. As I understand it, the flashover is a puncture of air near the surface and does not depend entirely upon the surface condition. It has been shown that under certain circumstances flashover has been improved by some dirt or oil on the surface and then there are conditions where flashover was lowered. Reduction of flashover may also be due to the fact that there is a slight pressure normal to the surface of the insulator which facilitates the production of corona in the air thus rarefied near the surface, as given in "Mechanical Forces at Contact Surface of Life Conductors and Insulators," by H. Stauffer in Revue Générale de l'Electricité, Nov. 24, 1923, page 765–72. The assumption made that there is an electrolyte on the surface of the insulator puts somewhat of a different aspect on this matter of flashover, as this supposition seems plausible if one observes the "tracking" produced by arcovers on insulators. However, as there are so many reasons given at the present time for flashover, other conditions, no matter how small, should be taken into consideration.

The author of this paper also states that if the insulator is of a smaller diameter the effective flashover is closer to the air puncture, which is true. But if all is a matter of area alone, then how would an insulator with grooves extending from one electrode to another in a spur gear-like shape behave? If all difficulties are eliminated by the simple apparatus used by the author, then what will be the effect of such an increased area in this gear-shaped insulator? Also, how would a tubular insulator, using electrodes which are doughnut-shaped so that the air inside and outside of the tube is the same, behave when subjected to flashover tests? Will it flash over inside as well as outside of the tube, or with repeated flashes where would it flash more, inside or outside?

In many instances an insulator, particularly one made of porcelain, will flash over at higher voltages when wet. Such an instance does not seem to be explainable by the electrolyte theory. It seems to be more explainable by the reference mentioned above, as the normal component is considerably reduced on the surface of the porcelain in contact with water. However, this may not be a complete explanation and possibly it is something more than just a coincidence that a completely wet insulator gives a much higher flashover strength.

One explanation may be that the potential distribution is considerably improved by the somewhat conducting film of water.

I also wish to mention at this point the Smith suspension wood insulator which has been in service for a number of years without failure. In this insulator a so-called hollow field was created, whereby the surface of the insulators separating the 2 terminals was in a field of such low density that flashover at the surface of the wood was made practically impossible. I don't think that this is a scientifically sound design, but just one of the things to take into consideration when flashover near the surface of insulators is being considered.

While it is possible that glass and porcelain may produce electrolytes on their surfaces, especially since glass is somewhat soluble in water, will electrolytes also be generated on the surface of other insulating materials not soluble in water? Following the author's argument, if we put the electrodes with the insulators in oil, or any other medium which can be made dry, in such a manner that no electrolyte is generated on the surface of the insulators, the flashover should be the same as the puncture of the oil without the insulators. I have not found this to be the case with commercial insulators of various shapes.

I agree that corrugations on the surface of a porcelain or any other insulator increase its flashover value, as has been proved by many observers. However, a general statement like this is not correct, as I have found from my experience that there is a certain definite proportion and relation between corrugations and the dimensions of the insulator. If the corrugations are too large, very often instead of flashing over the corrugations are punctured. This may also happen to smaller corrugations when flashed over in oil. In other words, corrugations are not only a function of the general dimensions of the insulator, but also depend upon the medium in which they are to be used.

On page 1067 is the following sentence: "The spread of the points in any individual test is practically equal to the spread of points from *radically different classes of structures*." There is some question as to the exact meaning of the words italicized. If it refers to design, I wish to say that I do not think that there are "radically different insulator designs." There are only different shapes which are so far from the correct design that none of these variations in shape can be considered to constitute a different design. Between the limits of commercial production such variations do not change their electrical characteristics, even though they may change the mechanical characteristics. However, if it means materials, then it would be much clearer if it were reworded, as the meaning is somewhat ambiguous in the present form.

There are designs, particularly of bush-

ings, in which the flashover voltages are higher than the ordinary ones. If we eliminate the question of flashover as a controversial one, we still can see that some bushings do not have streamers, but only corona discharge up to flashover potentials. I know of at least 2 such designs, one in this country and one in Germany.

I believe that in the matter of insulation design there is too much empiricism and, therefore, papers like this should be very much encouraged, since there is a great deal to be done to overcome the tradition built on erroneous conceptions. Furthermore, there should be more fundamental research done, not to prove a commercially advantageous point, but to get to the bottom of scientific truth and to establish relationships.

F. W. Maxstadt (California Institute of Technology, Pasadena): In the second paragraph of his comments, Mr. Barrow objects to the explanation that higher impulse than normal frequency arcover strength is due to time consumed in the evaporation of the electrolyte film from the insulation surface. His criticism is justified when commercial insulators with flanges or with shield rings spaced a smaller distance than the useful length of the insulator surface are under consideration. In such a case needle gap or rod gap conditions should apply, since a major portion of the ultimate flash is in air alone far removed from the insulation. The well-known time lag is thus due to lack of abundant initial ionization. The evaporation suggestion applies more specifically to the simple test specimens whose fundamental properties were reported. They were in homogeneous electric fields which notably exhibit for air alone almost no time lag or distinction between normal frequency and impulse breakdown. It is, however, not true that "both normal frequency and impulse arcovers respond similarly to corresponding changes in humidity." Torrok and Archibald show in their paper, "Suspension Insulator Assemblies," A.I.E.E. Transactions, volume 51, 1932, page 684, figure 4, that up to 2 microseconds time lag there is no difference between wet and dry impulse arcover voltage and up to 20 microseconds the difference is only about 8 per cent, whereas the ratio between normal frequency arcover for, say, 30 per cent relative humidity and wet has been shown on page 1063, figure 2, of the present paper to be 3 to 1 or 2 to 1, depending upon which experimenter's results are chosen.

It is very common to accept empirical data such as the value of 2 per cent increase in flashover voltage per grain increase in absolute humidity. The practice simplifies certain comparisons and small extrapolations and in the absence of better knowledge is to be tolerated, but if a true curve of variation is known, the narrow limits of satisfactory application of the simple rule are evident. If one did not know a magnetization curve beyond the straight line portion he would be justified in assuming, for convenience, constant permeability but we are not content with such treatment of the magnetic quantities, so why be content with such for the relation of humidity to arcover voltage? It is only a fortuitous circumstance that makes part of the arcover voltage vs. absolute humidity curve follow a straight line. There is no physical or other basis for the relation and since the absolute humidity scale does not indicate the point of discontinuity where dry conditions change over to rain, it should be discarded and a relative humidity scale substituted so as to show the true condition of the atmosphere.

Table I—Arcover Strength of 7.62 Cm Bakelite Rod, Smooth, With Varying Relative Humidity

Temperature 20–24 deg C, barometer 74 cm, protective resistance 0.2 megohm, flat electrodes with curved edges 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv per Cm	Per Cent Relative Humidity
153	20.2	33
154	20.3	36
153	20.2	35
152	20.0	38
146	19.2	48
118	15.5	63
115	15.1	70
74	9.7	95
73	9.6	95
71	9.3	98
41	5.4	Wet

Table II—Arcover Strength of 9.3 Cm "Pyrex" Rod, Smooth, With Varying Relative Humidity

Temperature 24–26 deg C, barometer 74 cm, protective resistance 0.2 megohm flat electrodes with curved edges 50 cycles, transformer impedance 10,000 ohms

Crest Voltage, Kv	Crest Gradient, Kv per Cm	Per Cent Relative Humidity
186	20.0	29
135	14.6	44
131	14.1	44
119	12.8	50
93	10.0	62
91	9.8	65
64	6.9	95
56	6.0	Wet

For comparison of smooth samples with the rods on which fine threads were cut, see tables I and II of this discussion. The bakelite piece is the same one reported in table I, page 1065, of the paper but without threads. The Pyrex piece is one of slightly larger diameter but the same material and tested in the same manner. A smaller series protective resistance was used for the tests in tables IV and V, also larger diameter electrodes, but those details do not spoil the comparison.

Regarding the small effect due to changes in humidity when the threaded rods were under test, it is to be expected that some effect will be observed since lack of symmetry, end conditions, and a little collection of dust make it quite unlikely that any specimen can be absolutely free from humidity influence in the normal frequency arcover. It is to be noted that the 6 per cent variation observed for the threaded rods is in place of a 3 to 1 variation for the smooth samples.

So far as the author knows no other test or explanation similar to the one concerning the ideal spacing of flanges as reported in the paper has appeared in the literature.

Practically, the linear relation for the air density correction is satisfactory but here again we want to know the true law of variation so as not to make grave errors when departing widely from the usual range. Air as a dielectric and insulators in air are sometimes used at several hundred pounds per square inch for purposes of obtaining greater breakdown strength. Either very low or elevated temperatures may also be encountered.

The influence on impulse arcover of geometrical details of the insulator, referred to in the closing sentence, may be determined for suspension insulators, pillars, and apparatus bushings by consulting A. O. Austin's paper, "An Improved Type of Limiting Gap," A.I.E.E. Transactions, volume 51, 1932, figures 1, 3, and 5, pages 677–9.

Mr. Hillebrand has pointed out a weakness in the statement in numbered paragraph 4 of the introduction to the paper, where uniform fields were suggested for transmission line insulators in order to obtain greater arcover voltages. I think, however, that if a large enough shield is used to obtain the desired results with respect to the insulator, it will almost completely cover the vulnerable portions of the tower cross arm and line conductor. Obviously the whole electric field of the line will have to be considered and at present big improvements are not in sight.

In his second paragraph Mr. Rah points out that "under certain circumstances" flashover has been improved by some dirt or oil on the surface. C. W. Rice (reference number 13) made some tests in uniform fields in which a coating of oil increased the arcover voltages of glass, hard rubber, and other substances. Between certain humidity limits dirt may improve the arcover strengths of commercial insulators.

The "very slender fibers" whose flashover voltages were abnormally high were almost microscopic threads. Insulators with grooves parallel to the electric field will act no differently from smooth cylinders. Doughnut-shaped electrodes do not produce the simple, uniform field used in the experiments reported, hence should be tested, until we have far more complete rules for insulator design than are now available.

The effect of moisture on a commercial insulator or any other insulator having small or nonplane electrodes seems to be to improve the voltage distribution up to a certain point beyond which more moisture brings about the short circuiting of useful surface.

A discussion of arcover of insulators under oil is not included in the scope of the paper, but keeping in mind that the best purification obtainable commercially still leaves 3 parts per million of water in the oil, there is no reason why the electrolyte explanation should not apply.

On page 1067 of the paper, radically different classes of structures mean everything tested, including cotton rope, smooth glass rod, smooth porcelain tube, commercial suspension strings, and insulator pillars as well as pin insulators.

News

Of Institute and Related Activities

The 1935 Winter Convention

IN SPITE OF New York's 17-inch snowfall, which occurred during the Institute's recent winter convention and which crippled traffic facilities in and about the city, attendance at sessions of the convention was good; a total of 1,114 members and guests registered. The percentage of attendants from outside New York City showed a further increase over last year; those registered from out-of-town (outside of District 3) this year comprised 38 per cent of the total registration, compared with 34 per cent for 1934, and 28 per cent for 1933.

Table I—Registration at Recent Winter Conventions

1935	1,114	1929	1,375
1934	1,227	1928	1,475
1933	1,099	1927	1,317
1932	1,429	1926	1,423
1931	1,589	1925	1,445
1930	1,607	1924	1,738

That the snowstorm had a direct influence on the total registration is evidenced by the fact that the first day's registration was 633 compared with 584 for the first day last year; the second days' figures were 301 and 433, respectively. Since the storm was at its height on the second day of the convention, the abrupt drop in registration on that and succeeding days was attributed directly to the storm. Of particular interest were the facts that attendance at the smoker and inspection trips was about double that of last year. These and other interesting facts are revealed by the accompanying tabulations. Brief reports on the principal features of the convention are given in the following paragraphs.

Opening Session

The convention was opened at 10 a.m., Tuesday, January 22, by C. R. Jones, chairman, general winter convention committee. Mr. Jones extended a hearty welcome to all members and guests attending the convention, particularly those from out of town. At the conclusion of his remarks, Prof. W. H. Timbie, vice president A.I.E.E. North Eastern District (number 1), read an address, "The A.I.E.E. as an Educational Institution," prepared by President J. Allen Johnson, who had been ill and was not sufficiently recovered to deliver it. In this address, President Johnson described the educational activities of the A.I.E.E. and urged members to "realize the dependence of their individual professional standings upon their continuing education, and make full use of the opportunities offered by the Institute." Full text of President Johnson's address may be found on pages 146–8 of this issue.

Following President Johnson's address, R. N. Conwell, chairman of the technical program committee, made brief announcement concerning the procedure to be followed in the technical sessions.

Technical Sessions

No detailed report of the technical sessions will be included here, inasmuch as all technical papers discussed have been published in previous issues of Electrical Engineering, and the discussions of these papers will be published in future issues. Most of the sessions were featured by lively and interesting discussions; those on general overhead line problems, transformers, and electronics were most widely discussed.

Demonstration Lecture on Illumination

Following the medal presentation ceremonies held in the Engineering Auditorium on Wednesday evening, January 23 (reported in detail on succeeding pages), a demonstration lecture, entitled "Artificial Light—the Engineer's Greatest Gift to Mankind," was given by A. L. Powell, president of the Illuminating Engineering Society, and member of the A.I.E.E. committee on production and application of light.

Mr. Powell traced briefly the history of lighting from early times down to the present, and demonstrated on the stage a great many types of lighting equipment ranging from the pine knot our forefathers used down to a modern 90,000,000 candle power searchlight. Apparatus illustrating some of the most recent advances in illumination was demonstrated, including applications of arc lamps in industry, medicine, and projection, as well as the newest forms of gaseous conductor lamps—the high intensity mercury and sodium vapor lamps. His lecture was illustrated also by many lantern slides, most of which were in color.

Attendance at this lecture was particularly good, about 350 being present, considering the fact that New York's recent snowstorm was at its height during the evening.

Inspection Trips

Continuing the plan introduced last year, the last day of the convention, Friday, January 25, was reserved for inspection trips. In addition to those held on Friday, several trips were conducted earlier in the week. To say which trips were most popular would be difficult because the attendance on some was limited to a previously determined figure. However, the trip to Warner Brothers moving picture studio and Hudson Avenue generating station of the Brooklyn Edison Company, and the all-day trip to the Edgewater plant of the Ford Motor Company, the Okonite-Callender Cable Company, and Wright Aeronautical Corporation were complete "sell outs" early on the first day of the convention; attendance on these trips was limited to 61 and 59, respectively.

The trip to Radio City Music Hall drew the largest attendance, 141 having registered for that event. Other popular trips with attendances were: General Electric House of Magic, 116; steamship "California," Panama Pacific Line, 87; radio patrol system, New York Police Department (2 trips), 84; and RCA Radiotron Company, 56. Smaller groups went on the several other prearranged trips. The trip to Newark (N. J.) airport and flight were cancelled because of unfavorable ground conditions resulting from the recent snowstorm. In all, 815 persons were registered for trips, compared with a total of 363 for the 1934 winter convention.

The committee in charge of arrange-

Table II—Analysis of Registration at Recent Winter Conventions

District	1933	1934	1935
New York City and Foreign (3)	791	812	694
North Eastern (1)	130	179	194
Middle Eastern (2)	132	161	153
Great Lakes (5)	23	40	38
Canada (10)	14	16	21
South West (7)	2	11	5
Southern (4)	4	5	6
North Central (6)	2	2	1
Pacific (8)	0	1	1
North Western (9)	1	0	1
Total	1,099	1,227	1,114

Table III—Attendance at Special Features of Recent Winter Conventions

	1933	1934	1935
Total registration	1,099	1,227	1,114
Smoker	650	550	1,025
Dinner dance*	350	464	442
Inspection trips	720	363	815

* Dinner-dance and dance-buffet supper combination introduced first in 1934.

ments for these fine trips was headed by S. A. Smith, Jr.; he was assisted by G. E. Dean, Henry Kurz, L. C. Miller, W. J. Quinn, H. O. Siegmund, H. B. Stoddard, E. R. Thomas, R. H. Twiss, W. Y. Vedder, and R. L. Webb.

Smoker

Departing from the custom of the past 6 years of holding the annual smoker in the Engineering Societies Building, the affair this year was held at the Casino de Paree at 254 West 54th Street, New York City. That this change met with the widespread approval of members of the Institute was evidenced by the fact that reservations had been made to the extent of the full capacity of the Casino well in advance of the opening day of the convention. A total of 1,025 members and guests attended this event.

Those attending the smoker this year enjoyed a full course dinner served in spacious surroundings and an excellent floor show after the dinner. As in former years, the high spot of the affair was the opportunity afforded the members to meet their engineering friends and to renew former acquaintances. Most important of all, perhaps, was the fact that all this was provided at a price lower than in previous recent years. The smoker committee was headed by George Sutherland; he was assisted by E. S. Banghart, R. F. Brower, C. A. Butcher, G. D. Edwards, W. H. Farlinger, W. H. Harden, William Jordan, J. E. McCormack, H. C. Schlaikjer, D. W. Taylor, E. F. Thrall, H. G. Wood, and L. A. Zima.

Dinner-Dance-Buffet Supper

For many years the outstanding social event of the Institute's winter convention, the dinner-dance, proved no less so this year. The combination dinner-dance and dance-buffet supper, which was offered for the first time last year, was so successful then that the innovation was continued this year. In addition, several lounge rooms for beverage service and for bridge and other games were provided this year; these added features proved to be highly popular.

A total of 187 members and guests attended the dinner-dance, 182 the dance-buffet supper, and 73 the combined dinner-dance-buffet supper, making the total attendance 442 persons. The committee in charge of this year's affairs consisted of C. S. Purnell, chairman, P. L. Alger, T. S. Bacon, C. M. Gilt, J. E. Goodale, H. L. Huber, W. A. Kietzman, Thomas Maxwell, J. A. McHugh, J. H. Pilkington, H. S. Sheppard, D. M. Simmons, and W. R. Smith.

Women's Entertainment

In addition to the regularly scheduled social events of the convention that are of particular interest to the women, a special program of entertainment was arranged to keep them occupied while their husbands were discussing the more weighty problems of electrical engineering. The luncheon and bridge at the Engineering Woman's Club, which has become a popular feature among women attendants to the convention, was held on Wednesday, January 23; more than 50 attended. Some 60 women visited the Good Housekeeping Institute, where tea was served, on Thursday. The radio broadcast by Walter Damrosch on Friday morning was attended by 25, and the tour of Radio City Friday afternoon by 46; the latter was followed by a tea in the British room.

In charge of the women's activities was Mrs. H. R. Woodrow; she was assisted by Mrs. C. R. Beardsley, Mrs. H. C. Dean, Mrs. A. F. Dixon, Mrs. Tomlinson Fort, Mrs. H. H. Henline, Mrs. A. H. Kehoe, Mrs. E. B. Meyer, and Mrs. G. S. Rose. A total of 75 women was registered at the convention.

Directors and Committees Meet

As is the usual custom, a meeting of the Institute's board of directors and meetings of several Institute committees were held during convention week. A report of proceedings at the board of directors' meeting, which was held on Monday, January 21, may be found elsewhere in this issue. Reports of the various committee meetings are scheduled for inclusion in the March issue. Meetings of the following Institute committees were held: automatic stations, communication, electrical machinery, electrochemistry and electrometallurgy, electrophysics, finance, instruments and measurements, lightning arrester subcommittee of protective devices, power generation, power transmission and distribution, research, standards, and technical program.

Much credit is due to the general winter convention committee for the splendid events arranged and for the splendid manner in which all arrangements were made. The committee was headed by C. R. Jones; he was assisted by T. F. Barton, C. R. Beardsley, C. O. Bickelhaupt, R. N. Conwell, A. F. Dixon, H. S. Osborne, D. M. Simmons, W. R. Smith, George Sutherland, and R. H. Tapscott.

Membership—Meeting the Bogey

Mr. Institute Member:

The membership committee has adopted the bogey of obtaining more applications for membership each month than for the corresponding month of the previous year. For the immediate months the results are:

	Number of Applications Received	
	1933	1934
September	15	55
October	45	98
November	53	78
December	58	60

Your contribution to this work is to send to the chairman of your Section membership committee the names of persons who you feel should be invited to join the Institute.

Your membership committee thanks you for your past helpfulness in this work and hopes for its continuance in even greater abundance. Perhaps you have a name or 2 in mind that you can send in—right now.

Everett S. Lee

Chairman National Membership Committee

A.I.E.E. Directors Meet at Institute Headquarters

The regular meeting of the board of directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, N. Y., on January 21, 1935.

Present: *President*—J. Allen Johnson, Buffalo, N. Y. *Past-Presidents*—H. P. Charlesworth, New York, N. Y.; J. B. Whitehead, Baltimore, Md. *Vice Presidents*—R. B. Bonney, Denver, Colo.; A. H. Hull, Toronto, Ont.; F. O. McMillan, Corvallis, Ore.; F. J. Meyer, Oklahoma City, Okla.; R. W. Sorensen, Pasadena, Calif.; R. H. Tapscott, New York, N. Y.; W. H. Timbie, Cambridge, Mass.; A. M. Wilson, Cincinnati, Ohio. *Directors*—L. W. Chubb, East Pittsburgh, Pa.; F. M. Farmer, New York, N. Y.; N. E. Funk, Philadelphia, Pa.; H. B. Gear, Chicago, Ill.; P. B. Juhnke, Chicago, Ill.; G. A. Kositzky, Cleveland, Ohio; Everett S. Lee, Schenectady, N. Y.; A. H. Lovell, Ann Arbor, Mich.; A. C. Stevens, Schenectady, N. Y.; H. R. Woodrow, Brooklyn, N. Y. *National Treasurer*—W. I. Slichter, New York, N. Y. *National*

Future AIEE Meetings

South West District Meeting,
Oklahoma City, Okla., Apr. 24–26, 1935

Summer Convention,
Ithaca, N. Y., June 24–28, 1935

Pacific Coast Convention,
Seattle, Wash., Fall 1935

Great Lakes District Meeting,
Indianapolis—Lafayette Section territory (date to be determined)

Secretary—H. H. Henline, New York, N. Y.

Minutes were approved of a meeting of the board of directors held on October 19 and of a meeting of the executive committee held on December 7, 1934.

A resolution was adopted in memory of George A. Hamilton, a former national treasurer of the Institute, who died on January 10, 1935. (The resolution appears elsewhere in this issue.)

Reports were presented and approved of meetings of the board of examiners held December 19, 1934, and January 16, 1935. Upon recommendation of the board of examiners, the following actions were taken: 3 applicants were elected and 3 were transferred to the grade of Fellow; 15 applicants were elected and 41 were transferred to the grade of Member; 123 applicants were elected to the grade of Associate; 257 Students were enrolled.

The finance committee reported disbursements for the month of December 1934 amounting to $13,883.86 and for January 1935 amounting to $18,939.58. Report approved.

Upon recommendation of the committee on Student Branches, authorization was given for the establishment of Student Branches of the Institute at Johns Hopkins University, Baltimore, Md., and Tufts College, Medford, Mass.

A resolution was adopted that the 1935 annual meeting of the Institute shall be held on Monday, June 24, at Ithaca, N. Y.

The following schedule of meetings for 1936, recommended by the committee on coördination of Institute activities, was adopted: winter convention, New York, N. Y., January 28–31; summer convention, Los Angeles, Calif., June 22–26; North Eastern District meeting, New Haven, Conn., early in May; Middle Eastern District meeting, Akron, Ohio, dates to be determined later.

Approval was given to revisions in the rules for the award of national and district prizes of the Institute as recommended by the committee on award of Institute prizes and the committee on coördination of Institute activities, to go into effect in connection with awards for the year 1935.

The board voted to sanction a plan for the accrediting of engineering schools which had been prepared by the Engineers' Council for Professional Development. (See item page 249, this issue.)

A report was presented of the special committee to review election procedure which had been appointed in accordance with the board's action in August 1934. Upon the recommendation of that committee, the board voted that steps be taken to amend the constitution in the spring of 1935 to permit the holding of the meeting of the national nominating committee (held early in December under the present provisions) during the winter convention, in January, with the resulting later publication of information concerning the nominations. This involves changing the date of mailing the election ballots from the first week in March to the first week in April, and changing the time limit for the return of the ballots from the first day of May to the first of June. The committee was continued in order that it may make a more thorough study of all aspects of the election procedure and submit a final report to the board of directors not later than January 1936.

Other matters were discussed, reference to which may be found in this or future issues of ELECTRICAL ENGINEERING.

Edison Medal for 1934 Presented to Doctor Whitney

THE Institute's highest award, the Edison Medal, was presented for 1934 to Dr. Willis R. Whitney for "his contribution to electrical science, his pioneer inventions, and his inspiring leadership in research," at a special session of the Institute's recent winter convention, Wednesday evening, January 23, 1935. Doctor Whitney has been an Associate member of the Institute since 1901, and is vice president and director of research of the General Electric Company, Schenectady, N. Y.

R. B. Bonney presiding over the ceremonies

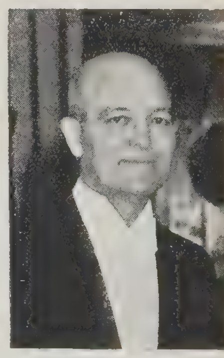
In the absence of J. Allen Johnson, president, A.I.E.E., R. B. Bonney, vice president, A. I. E. E. North Central District (Number 6), Denver, Colo., presided over the ceremonies. After brief introductory remarks, Mr. Bonney introduced Mr. C. E. Stephens, chairman, Edison Medal committee (for full personnel of committee see page 1332 of the September 1934 issue of ELECTRICAL ENGINEERING) who spoke briefly regarding the history of the medal and recipients during previous years.

Following Mr. Stephens's remarks, Mr. H. H. Barnes, Jr., past manager (1910–13) and past vice president (1913–15) of the Institute read an address briefly touching upon some of the high lights of Doctor Whitney's career, prepared by Dr. E. W. Rice, Jr., past-president (1917–18) of the Institute, who was unable to be present. Doctor Rice's address as read by Mr. Barnes follows.

High Lights in Whitney Career Outlined by Dr. E. W. Rice, Jr.

"I will not consume precious time in tracing the history of our medalist, as it already has been set forth in 'Who's Who' and other publications. It is well known that Doctor Whitney has received degrees in course and degrees honorary; that he is many times a doctor—doctor of science, doctor of philosophy, and even doctor of laws—a teacher, inventor, executive, member and past-president of many scientific societies, trustee of institutions of learning, a notable chemist, and now his friends are delighted that he should be awarded the electrical engineers' great prize, the Edison Medal.

"I regard it as a great honor that I should be selected to give a few reasons for the bestowal of this medal by his fellow engineers. Whitney very early in his professional career showed the qualities that have made his career so useful and notable. Doctor A. D. Little says in substance that this early work was in the field of chemistry, to which by 'brilliant experimental work, he added much to our knowledge of solubility of colloids and the corrosion of metals, the effect of the ions on the precipitation of colloids, he found that the corrosion of metals was an electrochemical process, and was among the first to focus public attention upon the great economical wastes resulting from preventable corrosion.' Naturally, we of the electrical profession believe that Whitney's greatest achievement has been his leadership of modern industrial scientific research, best exemplified by his administration of the research laboratory of the General Electric Company at Schenectady, N. Y.



C. E. Stephens outlines the Medal history

"Most of the years of my life have been devoted to engineering work, and it has been my good fortune to meet many of the distinguished engineers and scientific men of the world. This acquaintance with scientific men should be taken into account in weighing the value of my opinion that we were particularly fortunate in obtaining Dr. Willis R. Whitney to take charge of our research laboratory. This new venture, a truly great industrial event, was initiated many years ago, at the opening of the new century. The time, the year 1900, was most propitious. Our company and its predecessors had had some 20 years' experience in manufacturing electrical material

The electrical industry had grown to a considerable volume. Elihu Thomson, Edison, and many others had made most of their original and important contributions to the art. The panic and depression of 1893 to 1896 had shaken things down. The prejudices and crudities of the pioneer days had largely passed away. We had learned that there was a field for all the various applications of electricity, whether of alternating current or of direct current, such as the arc lamp, incandescent lamp, and electric street railway, and we were busy welding these together.

H. H. Barnes, Jr., reads Doctor Rice's address

"The opinion seemed to have been generally held that no radically new development could arise. Copper was the best conductor of electricity; iron the best for magnetism; carbon the best for electrodes of arc lamps, for filaments of incandescent lamps, and for brushes for commutators. As far as we could see, it was likely that these materials always would remain the best for these respective purposes. Such at least was the opinion of most engineers. However, there were a few who thought differently; and it was at this period of comparative calm that the research laboratory at Schenectady was started. The research laboratory started most modestly in a small way, with few men and few facilities, and increased in size only as it demonstrated its usefulness.

"The first 'valuable find' that resulted was in that borderland between chemistry and physics that has proved such a fruitful field for exploration. This was the metallized carbon filament for incandescent lamps. It resulted from an experiment by Whitney to see if he could prevent the blackening of incandescent lamp bulbs, which limited the useful life of the lamp. As has been often told, he placed some treated carbon filaments in a high temperature electric furnace he had devised, and found when these filaments were tested afterward in lamps that he had produced a new product, a new type of filament, one in which the electrical resistance had a positive or metallic characteristic. The resistance of the existing carbon filaments decreased with temperature, or, as it is called, had a negative characteristic. Whitney thus was able to produce a lamp that was at least 25 per cent more efficient, that is, gave 25 per cent more light for the same energy, with even a longer life than the standard lamp. This was a most remarkable contribution and naturally made us all happy. Also, it at once established the practical value of the research laboratory.

"I shall never forget the beautiful and convincing method by which Whitney arrived at the best 'prospect' for a metal filament. This was back in 1902. Osmium had shown an efficiency greater than carbon. John Howell pointed out that this shook our belief in the infallibility of carbon as a filament. It is true osmium was too rare, but it was more efficient than carbon, so there might be and probably was some other metal. Platinum and iridium had been tried and failed. Whitney took up the problem and proved to our satisfaction, by reference to the periodic law, that of all the remaining elements whose properties were unknown, tungsten and thorium were the only ones that theoretically could possess the necessary properties of high resistance and high melting point.

"It is not my purpose to describe the subsequent history of the laboratory under Doctor Whitney's direction, the story of the production of ductile tungsten, the new X ray tube, and the cathode ray tube by Coolidge; of the discoveries and inventions of Langmuir in high vacua and electronics, the gas filled lamp, and atomic hydrogen welding. This has been told often and told better by others.

"No one, however, will ever know the actual extent of his contribution. If was his fixed habit for many years to visit every room in the laboratory daily, and to offer freely the suggestions that came from his fertile mind, but without attempting to take the credit that lesser men would have deemed merely their right. If he had elected to pursue the solitary path of the inventor, he doubtless would have become one of the world's most famous and prolific inventors; but fortunately he saw and seized an opportunity for greater service, the building of a great research organization. So he sacrificed his personal researches and devoted less of his time to scientific discoveries and concentrated on the making of men.

"After he became director of research, he found time, incredible as it may seem, to make a number of personal contributions in addition to the metallized filament already mentioned. He discovered that, contrary to prevailing ideas, the positive electrode was not an essential factor in an arc lamp, and contributed the nonconsuming positive electrode used in the well known magnetite lamp.

"He discovered the effect of high frequency radio waves in producing artificial fever. By his own experiments he demonstrated the usefulness of such treatment in curing certain diseases of dogs, and stimulated the medical profession to develop its application to the relief of various human ailments.

"To the broadest scientific knowledge, Whitney added a contagious enthusiasm and undaunted courage, and insatiable curiosity. He is a keen but kindly critic, yet generous to a fault. He won confidence; disarmed suspicion; dissipated jealousy. He was not afraid to surround himself with great men, and made every effort to secure the services of the brainiest men in science. He secured Coolidge and Langmuir, Hull, Hawkins, and many others, and opened to them the door of opportunity and kept it open.

"Thus he has built up an organization that, inspired and stimulated by his leadership, has performed wonders. In a very real sense the work of his organization has been his work. His success is demonstrated not only by the material results but by the confidence and affection that he has inspired in all with whom he has come in contact. He deserves all the honors and the credit that have been showered upon him by a grateful and appreciative world, and it is characteristic of the man that he always accepted such honors as in trust for his organization.

"It was also characteristic of Whitney that he never thought of himself, that he never wanted fine offices, or expensive buildings or equipment. He was ever impatient with any procedure that took time from experiments, red tape, committee meetings, and even reports; he merely tolerates and omits them whenever possible.

"He is preëminently one of those rare men who are sufficiently expert to pass with certainty on suggestions of abnormally good minds. He allowed himself, as he says, 'To be led by Nature, instead of trying to force Nature along lines seemingly desirable.' While it is true that the shop and the soil are great sources of wealth, the human intellect excels all, and a research laboratory is a wealth producer par excellence because it is an organization of men who systematically use their brains to reach for new things, new facts, new combinations, new truths."

Doctor Whitney Describes Experiments on Lamp Filaments

Immediately following the reading of Doctor Rice's address by Mr. Barnes, Mr. Bonney presented the medal and engraved certificate to Doctor Whitney, who responded as follows:

"Perhaps no other person could feel a greater pleasure at this honor than I. I lived through the whole period of Mr. Edison's historical work. I recall seeing one of the first carbon filament lamps, when it was thought to be just an interesting novelty. It looked pretty small compared with the existing arc lights, and it could not be installed in houses since no one had wiring for it.

"Now, for nearly 35 years, I have been in particularly close contact with incandescent lamp work, as well as with many of those other electrical developments so dear to Mr. Edison himself. It seems fitting for me at this time, therefore, to add a little to the records of studies that we at the research laboratory of the General Electric Company made to continue Mr. Edison's researches on carbon filaments.

Doctor Whitney responds

"In the early days of our laboratory, we studied experimentally all those chemical elements we could procure that had higher melting points than platinum or had not been melted. The father of the incandescent lamp had worked on platinum as a filament and there were still several promising metals that had never been made into filaments. Carbon still seemed promising, too, and for many years we continued re-

search upon it. It is bad engineering to assume that a thing is perfected. It is usually improved by some unforeseen process.

"At that time the carbon filament had undergone many improvements which hardly warranted general publicity. It had not stopped at the earlier carbonized threads, or the slivers of bamboo. When I think of possibilities, as they sometimes develop, I wonder if someone might not yet discover another superior form of carbon.

"Remember that I can recall the time when no one had made graphite, thought it was found in nature, and also that Moissan had shown me tiny diamonds he had made from coke. Black diamond, or bortz, was known, and the question was, 'How many other forms or isomers of this fertile carbon can we find or make?' Moreover, efficient arc lamps used carbon for electrodes, and carbon motor brushes had displaced the metal ones. It seemed as though carbon was particularly designed for electrical services.

"One line of our own work should be described, if for no other reason than to make available to some future student of carbon, details of speculation and of knowledge not generally available. The product itself was described as a new form of carbon by Mr. John W. Howell before the A.I.E.E. in 1905.

"About 30 years ago, the best incandescent filament was a combination of 2 different allotropic forms of carbon, a coke and a graphite. The filament had actually a core or base of coke, carrying a complete coat, shell, or sleeve of graphite carbon. This core was made by dissolving cotton in zinc chloride solution and squirting the product through suitable dies into a coagulating or fixing liquid. This thread was then washed, dried, shaped, and carbonized. The carbonizing consisted in packing the formed loops into fireproof crucibles with a protective mass of previously carbonized peat dust. This protected the filaments from burning. Each such base was at best a very poor lamp filament. It was then heated individually by electric current while held in a low pressure of hydrocarbon vapor. By the proper selection of the vapor, its pressure, and the time and temperature of the treatment, a thin, shiny, dark gray coating was put over the dead black carbon base. The criteria, chemical and physical, that were then available forced us to call the base a coke carbon and the hard, shiny coat a form of graphite.

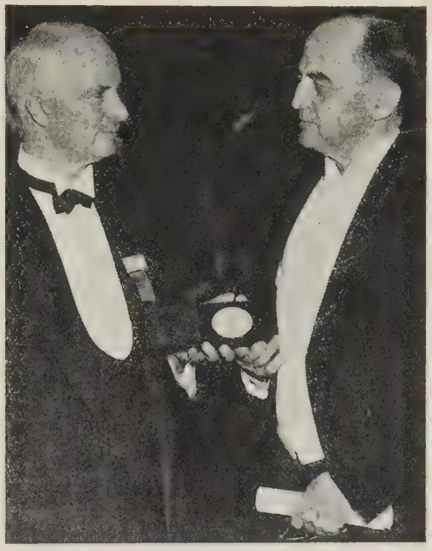
"Our production of a new kind of graphite at this time permitted an improvement in the lamp that was equivalent to about 20 per cent in luminous efficiency. This developed into the so-called metallized-filament lamp.

"Its actual discovery illustrates one of the pleasures of research—the uncertainty. It is not always necessary to have the right hypothesis for a research, provided the suggested work can be carried out. Poor hypotheses sometimes lead to new utilities, just as the wrong horse sometimes wins the race. The original idea responsible for the production of metallized carbon might occur to someone else and seem as intriguing and promising as it did to us. This makes me want to explain it.

"As the base filament was made from cotton, it contained practically all the mineral matter of that original cellulose; that is, it left a little mineral ash on being burned in air. This ash was a complex mixture of silicates of iron, calcium, aluminum, and other metals, and contained combined oxygen. At the temperature of the gas furnace, which carbonized the filaments, part but not all of such oxides would be reduced. It seemed probable that small quantities of oxides, such as magnesium, aluminum, calcium, and silicon, might not be reduced. They would probably continue as oxides in the finished filament. Could they do harm there? That seemed possible. It was an old story even 30 years ago to connect accurately the length of useful life of a lamp with its burning efficiency at definite voltage. One of the limits to useful life was the blackening of the inside of the bulb, and the blackening was carbon from the filament.

"When a lamp had lost 20 per cent of its initial candlepower, whether from blackening or other causes, it was called dead. Good lamps lived under the test conditions 500 hours. The vacuum was as good as we could make it; but we knew that while this actually improved during early burning, it grew poorer as time went on. The question naturally arose, 'Can there be a slow reaction within the burning filament between residual oxides and carbon?' If so, the blackening could be explained very simply. I became quite excited about this point.

"Chemists knew that coke burns to carbon monoxide and dioxide, and that under temperature conditions existing within the lamp 2 molecules of the monoxide could react to set free one atom of carbon and form one molecule of carbon dioxide. The atom of carbon certainly would deposit on the glass walls and begin the blackening; but that constituted only an infinitesimal portion of the possibilities, for the molecule of dioxide most certainly would come into contact with the hot filament and oxidize it so that we could have 2 new molecules of the monoxide. These at lower temperatures could react as before, give us our second free carbon atom and a new dioxide molecule, and so on, *ad infinitum*. In other words, a single molecule of carbon dioxide might act as a perpetual 'ferryboat' to carry carbon from filament to glass We could visualize the dioxide, and the transported carbon was evident.



Dr. Willis R. Whitney (right) being presented the Institute's 1934 Edison Medal by R. B. Bonney, vice president of the Institute representing the North Central District, during the special presentation ceremony on January 23, 1935, which was part of the recent winter convention

"It was this that led us to try to remove the very last traces of oxides from the base filaments. At this time we had already made electric furnaces for much higher temperatures than those attained by gas furnaces. The furnace was a carbon tube packed in powdered carbon. It could be heated, by passing current through it, to such a temperature that it sublimed or distilled away very rapidly at the hottest part. The temperature was about 3500° C. For our work we actually destroyed the furnace by its sublimation at each heating of a filament charge.

"Our first experiments did not disclose any useful improvements in the lamps, but there were so many possible explanations of the failure that we attempted a more careful repetition.

"Our stock of filaments had been taken from the factory and our lamp tests were made there. Through some error in shipment, the new stock of filaments were not the simple base or coke material we had used previously, but were the finished, complex filaments with their graphite coats. When these were put through our heating process, they came out looking very bad indeed. The surface was wrinkled and irregular, and there were countless hollow warts or tiny burst balloons of graphite on them. These balloons had been blown up by the gases coming from the impure coke base, which could not penetrate so easily the semi-liquid or dense graphite coat. In spite of their condition the life of these filaments in lamps was better than usual. I was sure of the value of the oxide hypothesis, and it seemed only a question of preheating the bases before putting on the graphite, in order to get rid of the irregularities.

"Mr. Howell, dean of lamp makers, early called our attention to the fact that we had made a new form of graphite, to which the improved quality of lamp was to be attributed. Perhaps we had sintered or melted the graphite coating into an unusually dense but continuous form by our combination of very high temperature with an atmosphere saturated with carbon. This would explain why it could not be done by heating the filament to the same temperature in vacuum.

"The electrical resistance of the graphite coat had been reduced to about $^1/_5$ of its previous value, and the temperature coefficient, like that of the pure metals, was positive. For this reason it soon was called metallized graphite. Later products, in which the base was heat purified and then with its added graphite coating again subjected to the electric furnace, gave us the filament for the improved lamp. Under these conditions it was no great disappointment to learn that the explanation of the new quality was not necessarily dependent on the starting hypothesis."

John Fritz Medal for 1935
Presented to a Son of the Late Frank J. Sprague

FOR "distinguished service as inventor and engineer through the application and control of electric power in transportation system," the John Fritz Medal and engraved certificate of award for 1935 were presented to Robert C. Sprague, son of Dr. Frank J. Sprague to whom the medal was awarded on October 19, 1934. Doctor Sprague died on October 25, 1934, 3 days after he had received notification of the award. Doctor Sprague was president of the A.I.E.E. 1892–93, and was elected an honorary member in 1932. The presentation took place during the evening of Wednesday, January 23, immediately following the presentation of the 1934 Edison Medal.

The John Fritz Medal is awarded not oftener than once each year, for notable scientific or industrial achievement, without restriction on account of nationality or sex. In memory of John Fritz of Bethlehem, Pa., one of America's great pioneers in the iron and steel industries, the medal was established in 1902 by friends and associates. It is awarded by the 4 national societies of civil, mechanical, mining and metallurgical, and electrical engineers, having a composite total of more than 50,000 members.

The first medal was given to John Fritz at a dinner for him on his eightieth birthday, August 21, 1902. Subsequent awards of the medal have been as follows:

1905 LORD KELVIN (HM'92). For his work in cable telegraphy and other scientific achievements.

1906 GEORGE WESTINGHOUSE (A'02). For the invention and development of the air brake.

1907 ALEXANDER GRAHAM BELL (A'84, M'84, and past-president). For the invention and introduction of the telephone.

1908 THOMAS ALVA EDISON (A'84, M'84, HM'28, and member for life). For the invention of the duplex and quadruples telegraph, the phonograph, the development of a commercially practical incandescent lamp, the development of a complete system of electric lighting, including dynamos, regulating devices, underground system, protective devices and meters.

1909 CHARLES T. PORTER. For his work in advancing the knowledge of steam engineering and in improvements in engine construction.

1910 ALFRED NOBLE. For notable achievements as a civil engineer.

1911 SIR WILLIAM H. WHITE. For notable achievements in naval architecture.

1912 ROBERT W. HUNT. For his contributions to the early development of the Bessemer process.

1913 No. award.

1914 PROFESSOR JOHN E. SWEET. For his achievements in machine design, and pioneer work in applying sound engineering principles to the construction and development of the high-speed steam engine.

1915 DR. JAMES DOUGLAS. For notable achievement in mining, metallurgy, education, and industrial welfare.

1916 DR. ELIHU THOMSON (A'84, M'91, F'13, HM'28, member for life and past-president). For achievement in electrical invention, in electrical engineering and industrial development, and in scientific research.

1917 DR. HENRY M. HOWE. For his investigations in metallurgy, especially in the metallography of iron and steel.

1918. J. WALDO SMITH. For achievement as engineer in providing the City of New York with a supply of water.

1919 GENERAL GEORGE W. GOETHALS. For achievement as builder of the Panama Canal.

1920 ORVILLE WRIGHT. For achievement in the development of the airplane.

1921 SIR ROBERT A. HADFIELD. For the invention of manganese steel.

1922 CHARLES PROSPER EUGENE SCHNEIDER. For achievement in metallurgy of iron and steel, for the development of modern ordnance, and for notable patriotic contribution to the winning of the great war.

1923 SENATORE GUGLIELMO MARCONI (HM'17). For the invention of wireless telegraphy.

1924 AMBROSE SWASEY (HM'28). For achievement as a designer and manufacturer of instruments and machines of precision, a builder of great telescopes, a benefactor of education, and the founder of Engineering Foundation.

1925 JOHN FRANK STEVENS. For great achievements as a civil engineer, particularly in planning and organizing for the construction of the Panama Canal; as a builder of railroads, and as administrator of the Chinese Eastern and Siberian Railways.

1926 EDWARD DEAN ADAMS (A'10). For great achievements as engineer, financier, scientist, whose vision, courage and industry made possible the birth at Niagara Falls of hydroelectric power.

1927 ELMER AMBROSE SPERRY (A'84, M'93, and member for life). For the development of the gyro-compass and the application of the gyroscope to the stabilization of ships and aeroplanes.

1928 JOHN JOSEPH CARTY (A'90, M'03, F'13, HM'29, member for life and past-president). For pioneer achievement in telephone engineering and in the development of scientific research in the telephone art.

1929 HERBERT HOOVER (HM'29). As engineer, scholar, organizer of relief to war-stricken peoples, public servant.

1930 RALPH MODJESKI. For notable achievement as an engineer of great bridges combining the principles of strength and beauty.

1931 ADMIRAL DAVID WATSON TAYLOR. For outstanding achievement in marine architecture, for revolutionary results of persistent research in hull design, for improvement in many types of warships and for distinguished service as chief constructor of the United States Navy during the World War.

1932 MICHAEL IDVORSKY PUPIN (A'90, F'15, HM'28, member for life and past-president). Scientist, engineer, author, inventor of the tuning of oscillating circuits and the loading of telephone circuits by inductance coils.

1933 DANIEL COWAN JACKLING. For notable industrial achievement in initiating mass production of copper from low-grade ores, through application of engineering principles.

1934 JOHN RIPLEY FREEMAN. Engineer—preeminent in the fields of hydraulics and water supply, fire insurance economics, and analysis of earthquake effects.

1935 FRANK JULIAN SPRAGUE (A'87, M'97, F'12, HM'32, member for life and past-president). For distinguished service as inventor and engineer through the application and control of electric power in transportation systems.

Roy V. Wright, present chairman of the John Fritz Medal board of award (the board consists of the 4 most recent past presidents of the 4 participating societies) officiated during the ceremonies. He first spoke briefly about the history of the medal and the man for whom it was established, then introduced Dr. Gano Dunn, president, J. G. White Engineering Corporation, and long time friend of the medalist, who outlined briefly the accomplishments for which Doctor Sprague is most widely known. His address follows:

Doctor Sprague's Career Sketched by Doctor Dunn

"On account of the death of Frank Julian Sprague after the award to him of the great distinction of the John Fritz Medal, but before its presentation, it is with a sense of deep sadness accompanied by a sense of pride, that I undertake the honor of setting forth the grounds on which the award of the medal was made.

"A mere enumeration of Sprague's accomplishments would be impressive, but when they are read in the light of the state of the electrical art at the time each accomplishment was produced, admiration for his results rises to the point of transcendent respect and recognition of genius.

"He stands out in the minds of engineers and of the informed public, as having given to the world the early constant speed motor, the electric railway, the electric elevator, and particularly the multiple unit system of train operation; in use all over the world. Each of these generic items, is, however, but the chapter heading covering hundreds of other auxiliary items playing into it which the world calls inventions also, but which Sprague used to delight in calling "solutions."

"Since the remarkable demonstration of respect and appreciation in this hall 3 years ago, on the occasion of his 75th birthday, when his work was recognized by the tributes of a distinguished audience who were present, as well as by large numbers who were absent, claims have been made in various quarters that Sprague was not the first in the conception of several of the items that have been attributed to him.

Roy V. Wright officiating over the John Fritz Medal ceremony

"Such claims always arise in the wake of great achievement. They have arisen against the names of James Watt, Robert Fulton, Elias Howe, Alexander Graham Bell, Thomas A. Edison, and others.

"Without conceding at this time the validity of any of these claims, although some of them undoubtedly have merit, attention should be called to the fact that what the world honors in the industrial field, as distinguished from the field of pure science, are the gifts it has received through accomplishment rather than the gifts of fractional and undeveloped conception.

"It is recognized that Shakespeare borrowed many of his plots, but the authors of those plots cannot successfully claim to have given us Shakespeare.

"With all this in mind, Sprague's fame in connection with the constant speed motor, the electric railway, the electric elevator, and multiple unit train operation, is secure.

"There are those here who will remember that in the early days of electrical distribution, the emphasis was upon lighting, accomplished by a system in which a direct current that was constant actuated arc lamps in series with each other. Hundreds of inventions were made to produce motors that would successfully adapt themselves to these systems of constant current supply and at the same time run at a constant speed. As a class these motors were fearfully and wonderfully made, and as a class they were unsuccessful, so that while electric lighting was growing on all sides, there was practically no electric power. Alternating current systems of distribution had not yet arrived and the Tesla motor was unborn.

"Edison's great conception of the constant potential multiple arc system of distribution as distinguished from the existent constant current series system, was a conception so great that it has practically superseded every other system of distribution today. He worked it out to enable the subdivision of consumption into small units, controllable without affecting other units in the system. It is probable that Edison realized also that in solving thus the problem of the distribution of electric lighting, with primarily the incandescent lamp in view, he was also solving the problem of the distribution of electric power.

"Following Sprague's resignation from the United States Navy in 1883, he was Edison's assistant for about a year. Impressed with the power possibilities of the constant potential system of distribution, which Edison had introduced into New York in the Pearl Street Station in 1882, Sprague set himself with brilliant success to developing a motor that would run at constant speed on constant potential systems. He not only produced the upright type of motor among others for this purpose, but introduced the differential series winding to compensate for a rather high internal armature resistance, which otherwise would cause a drop in speed. The net result of all this was that Sprague motors began to be used everywhere on Edison circuits and were finally officially endorsed by the Edison companies on account of their simplicity, effectiveness and the growing use of electric current which they began to bring about.

"For the manufacture of these motors, and with an eye on the application of electric power to street cars, Sprague, in 1884, organized the Sprague Electric Railway and Motor Company.

"But it was not until 1887, that he astonished the technical world by taking a contract to build and equip in 90 days, an electric street railway in Richmond, Va. The problems that were successfully and brilliantly solved in the design and construction of the Richmond road and its equipment, and the methods by which Sprague met emergency after emergency arising out of unexpected failures of details and out of unforeseen requirements, so impressed the technical world as well as the public, that they founded the title by which he was called: "The Father of Electric Traction."

"So spectacular was the accomplishment of Sprague in the Richmond road, notwithstanding many imperfections that were later removed, that within 2 years, his company had closed contracts for 110 more roads, and in 1890, it was merged with the Edison General Electric Company, which later became the General Electric Company.

"With the taking over of his electric railway work by the Edison General Electric Company, Sprague, like Alexander, sighed for more worlds to conquer, and turned his attention to the elevator field, which was becoming increasingly important with the increasing height of buildings, made possible through fundamental developments in the art of steel making. Sprague regarded this as turning his attention from the field of horizontal to the field of vertical transportation.

"Hydraulic elevators had reached an unparalleled perfection for ordinary heights. Steam elevators were considerably used, and there was some use of electric elevators in the form of slow moving second class equipment, but all of these failed adequately to meet the demands for higher speeds and longer runs called for by increasing skyscraper construction.

"Sprague saw from his electric railway experience how increased speeds had markedly increased line capacity and earnings, and with this experience in horizontal transportation before him, he foresaw that similarly increasing the capacity of elevator shaftways would not only save the time of passengers in transit but would also favorably react on the earnings of tall buildings, of which the height was already beginning to be limited by the greater and greater proportions of total floor space necessarily subtracted by the shaftways of slow running elevators.

"In conjunction with Charles R. Pratt, he developed the Sprague-Pratt Electric Elevator, and in 1892, organized for the purpose of manufacturing this and other advanced types of electric elevators, and controlling mechanisms, the Sprague Electric Elevator Company, which company built nearly 600 elevators when it was absorbed by its then greatest competitor, the Otis Elevator Company.

"In 1926 Sprague made the remarkable proposal of operating 2 elevators in the same shaft, the lower one for local and the one above it for express service, rendered possible by the perfection of the controlling devices which he had invented.

"The merit of Sprague's elevators was fully as much, if not more in the inventions devised for their control, as it was in the inventions devised for their mechanical operation. High speed demanded not only freedom from oscillation on arrival at a floor, but ability to control that arrival with precision and smoothness.

"Electrical devices in the hands of Sprague became ideally adapted to such control to an extent that led to the development of high speeds with safety and comfort and to the working out of the unattended automatic or so-called push button type of elevator now so much in use in private houses, apartment houses, and other locations, where the traffic is not dense enough to require an operator.

"While developing the high speed and the automatic electric elevators in which the control of the hoisting machinery was effected indirectly by small pilot motors and other control devices located near this machinery, these pilot motors in turn being operated by signaling circuits from the car, Sprague saw that through the principle of pilot operation and signal circuit control, he had discovered not only a means of effectuating more rapid, more precise, and more flexible control of a single car, but also a means of controlling cars in groups in all sorts of predetermined and un-predetermined combinations with each other.

"The demand for group control did not exist at that time in the elevator field, but Sprague with the unerring insight of a great inventor, saw what could be accomplished with such group control if applied to the railroad field, where the idea of concentrating the whole tractive power of a train in a locomotive at its head held sway.

Doctor Dunn sketches Doctor Sprague's career

"Trolley cars had been accustomed to haul trailers but that is about as far as making up a train of trolley cars had got, because of the impossibility of coördinating the tractive effort of more than one power car in a train.

"In 1895 Sprague conceived his multiple unit system for the operation of trains of trolley cars and about 1897 applied it to the operation of the Southside Elevated Railroad in Chicago. His multiple unit system abolished the customary locomotive at the head of a train and distributed its power elements along the train without reducing the tractive effort which the train as a whole could exert upon the rails in starting. As a matter of fact, the tractive effort was not only not reduced but greatly increased. By this means so great an increase in acceleration was made possible, that the limit was no longer the point at which the wheels of a locomotive would slip, but the point at which passengers would be made uncomfortable or, if standing, be thrown to the floor by the rapidity with which the train got under way.

"This increased acceleration brought about by the Sprague multiple unit system so greatly increased average speed that under certain conditions it nearly doubled the capacity of a road without increasing at all the maximum speed at which its trains must run. These accelerations resulting in vastly increased line capacity, were not the only advantages deriving from Sprague's great invention. Trains could be made up at will of any number of units, large or small, and could be broken up at junction points and combined at other points without reference to presence or absence of locomotive equipment.

"It has not been attempted to cite all of Sprague's work, which would be impossible on this occasion, but it is necessary to point out that the great accomplishments that have been enumerated have in every case

(*Continued on page 245*)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With the Inquiring Photographer

At the 1935 Winter Convention: the Edison and John Fritz Medal Presentation Ceremony and the Annual Dinner-Dance.

(1) Director H. R. Woodrow pays careful attention to a good story

(2) Past Presidents Arthur E. Kennelly (left) and Bancroft Gherardi awaiting the medal presentation ceremony

(3) National Secretary and Mrs. H. H. Henline in conversation with W. K. Vanderpoel (right) who was a member of the Institute Board of Managers 1923–27

(4) George Sutherland (right), chairman of the committee that staged a sell-out smoker at the Casino de Paree, learns from D. H. Moore and Lindsey Ellms (left) that the customers all survived

(5) F. M. Feiker (left), executive secretary of American Engineering Council evidently impressed General Robert I. Rees, S.P.E.E. representative on the executive committee of the Engineers Council for Professional Development

(6) D. M. Simmons, chairman of the Institute's power transmission and distribution committee apparently did not put his story across so well with Mrs. George Sutherland

(7) C. O. Bickelhaupt, chairman of the Institute's publication committee interests Mrs. H. P. Charlesworth; Past President Charlesworth looks on

(8) Past President Bancroft Gherardi discussing a point of mutual interest with Mrs. K. S. McHugh while the inevitable chicken gets cold

(9) J. W. Barker, chairman of the Institute's committee on the production and application of light, commands the attention of Mrs. Robert I. Rees (left) and Mrs. Walter I. Slichter

(10) J. K. Sprague (son of the late Dr. Frank J. Sprague, 1935 John Fritz Medallist), Past President J. B. Whitehead, and Treasurer Walter I. Slichter (right) await the medal presentation ceremony; George T. Seabury, national secretary of the American Society of Civil Engineers, may be seen between Doctor Whitehead and Mr. Slichter

(11) J. O'R. Coleman, engineer for the Edison Electric Institute and member of the Institute's communication committee, apparently putting on a fire-eating stunt while H. R. Huntley (extreme left) observes, perhaps in awe

(12) Chairman C. S. Purnell (seated) of the dinner-dance committee checking notes between courses with Chairman Sutherland of the smoker committee

(13) Vice President Royal W. Sorensen of Pasadena, Calif., through whose consistent long-time efforts the 1936 summer convention will go to Los Angeles, evidently was startled to find himself in the camera's eye

(14) Vice President F. O. McMillan of Corvallis, Oregon (right), might have been discussing E.C.P.D. matters with General Rees across Mrs. Henline's dessert

(15) Edward B. Meyer (left), president-designate, present vice president, and many-time chairman of important Institute committees, seems to be not too deeply impressed by A. H. Kehoe's story

Photos by Harald J. Torgeson

spread their influence vastly beyond their own fields.

"The constant speed motor favorably reacted upon the introduction of electric power into factories, with all that that has meant; the electric street railway, now in eclipse, owing to the development of free wheeled rubber tired vehicles, was the progenitor of the present suburban and subway electric train; the high speed electric elevator with its competent indirect control, has reacted upon the building industry and the development of great cities.

"The creation of the multiple unit system of train operation and control has brought about the daily transportation of millions, with speed and safety, which, without it, would be impossible.

"Sprague had a dynamic personality, characterized by an insatiable passion for invention. He fired the enthusiasms and the ambitions of unnumbered others to great achievement in the electrical and related fields. His qualities were the admiration and delight of hosts of friends, who will see in the discernment of the John Fritz Medal board of award which selected Frank Julian Sprague for the medal, a complete vindication of the purpose of the founders of the medal and an additional tribute of honor to the name of John Fritz as well as to the name and fame of Frank Julian Sprague."

Response of Robert C. Sprague

Following Doctor Dunn's address, Mr. Wright presented the medal to Robert C. Sprague, son of the late Dr. Frank J. Sprague, who responded as follows:

"I am here tonight as a representative of my father's family to receive the award of the John Fritz medal to my father, Mr. Frank Sprague. I only regret that he is not here himself to acknowledge the award and to hear the many gratifying things which have been said about him and his work by the distinguished speaker who has paid tribute to him here tonight.

"Although destiny and his life span prevented his being here, you will be glad to know, I am sure, that he received notice of the award and was fully cognizant of its significance before he died.

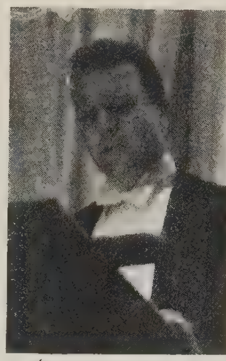
"I was with him for a short time on Monday night, October 22nd, when my mother read to him the notice of award from Mr. Tally, chairman, at that time, of the award committee, and dated October 19th. His mind was very active then, as it was until the end, and he spoke of his great pleasure at this further recognition of his work by a committee representing the 4 great national engineering societies.

"I was fortunate as a small boy to have been present when my father was awarded the Edison Medal in 1911, and going over some of his papers recently, I was impressed with many parts of his acceptance of that award. Many of his thoughts at that time are equally applicable on this occasion, so I think it would be proper for me to read excerpts, which, I am sure, express what he would like to convey to you tonight.

"His acknowledgment started: 'I would indeed be strangely constituted if I were not deeply sensitive to and profoundly moved by so great an honor as this present award. In truth, I am glad to be thus honored and to pretend otherwise would be to violate one of the essential tenets of our profession, which above all, teaches us to be exact in statement and that I do with a very full heart.

"'I am not, however, unmindful of a first-hand knowledge of my own shortcomings and I know how unwarranted it would be to assume this compliment is limited to a personal recognition of the work which, as an engineer, it has come to my hand to do, and the possibility of which is so largely a matter of professional training, ripeness of the times, and existence of opportunities.

"'The committee, it is true, has been good enough to individualize me in this happy manner, but what would have been the result if the loyal support, vital at critical times, had not been forthcoming? Rarely, is there an industrial development on any large scale except by the combined effort of many people. I would, therefore, be indeed remiss if I did not thank you not alone for myself, but also on behalf of my beloved alma mater, the United States Naval Academy, and for those who in business and professional ways when discouragements crowded thick and fast, as well as when hopes ran high, were an ever-present help.'



R. C. Sprague responds for the Sprague family

"In referring to Mr. Edison at that time, and dad's comments would be equally applicable in referring to Mr. John Fritz on this occasion, he went on to say, 'It is the fortune of but few for whom training, inclination, opportunity and fortuitous circumstances combined to give the privilege of blazing the path of new industries, but in any event, one can be glad to be a member of that profession which, above all others, forms the advance guard of civilization and typifies the restless creative energy of our age and which is, of necessity, imbued with the romantic spirit of adventure.'

"Referring again to his beloved profession, he said, 'The profession of engineering is not only an honorable one, but according to biblical history, it is one of the oldest. An engineer is trained not only to ask questions and find weaknesses, but to correct them, to build up, not to pull down, to create, not to destroy. His training is along the lines of exactness and honesty and investigation and conclusion, and designing and construction constitute the very foundation of his professional ethics.'

"In conclusion, he said, 'So, too, in our profession, there are surely new paths to blaze, fresh histories to make, unending worlds to conquer. The heritage of greatest value which we can leave to those who bear our names is that of high aims realized and creative work well done.'"

Student Convention Held at Harvard University

The first New England student convention including all the A.I.E.E. student Branches in the North Eastern District, number 1, was held somewhat over a year ago (December 1933) under the sponsorship of the Massachusetts Institute of Technology. This convention was so successful that it was decided to make it an annual affair. As a result, the second student convention of this District was held December 15, 1934, at Cambridge, Mass., under the sponsorship of Harvard University.

The afternoon session began at 2:30 with an address of welcome by Dean Harry E. Clifford of Harvard Engineering School. This was followed by an address "A New Field for Engineering Graduates," by Prof. W. H. Timbie of Massachusetts Institute of Technology and Institute vice president for District number 1. Albert Haberstroh, vice chairman of the Harvard Branch, opened the technical sessions with papers by members of the Branches; these papers were followed by a short discussion. The papers, in order of presentation were as follows:

Ultra High Frequency Measurements, by T. F. Hammett, Worcester Polytechnic Institute.

A Study of 3-Phase Open-Y Connections of Transformers, by H. B. Fancher, Brown University.

A High Fidelity Sound System, by R. Applegarth, Massachusetts Institute of Technology.

This Business of Amateur Radio, by R. W. Bradley, Tufts College.

Measurement of Losses in Oscillator Tubes by Thermal Methods, by F. P. Cowan, Harvard University.

After the discussion period, R. T. Gibbs of the Harvard Engineering School described the high voltage laboratory, following his talk by a spectacular demonstration. The students were then divided into 2 large inspection groups. The first group inspected the dynamo, telephone, and rectifier laboratories in Pierce Hall, and the 100,000 volt storage battery in the Cruft laboratory. The second group inspected the communication laboratory and the 100,000 volt battery, both in Cruft laboratory. There were also a few scattered groups headed by special students or instructors. Professor Cassagrande demonstrated some phenomena connected with the soil mechanics laboratory, and Professor J. P. DenHartog conducted experiments in the applied mechanics laboratory.

For dinner, the students were again divided into 2 groups, one-half going to Winthrop House and the other to Adams House. Those present from other colleges were thus given a chance to look over the new Harvard house plan and see it in operation. After dinner, the groups returned to the Cruft laboratory, where Dr. A. A. Noyes gave a lecture and demonstration of experiments on "supersonic phenomena." High frequency sound modulation was compared with high frequency radio modulation. Following the main lecture, Prof. H. R. Mimno demonstrated his new short wave transmitter to a number of interested students.

As reported by R. B. Power, in charge of registration, there were 111 registered at the convention, divided as follows:

Harvard University	26
Massachusetts Institute of Technology	22
Worcester Polytechnic Institute	13
Brown University	16
Northeastern University	12
Tufts College	9
New Hampshire University	5
University of Vermont	4
Yale University	3
Rhode Island State College	1
Total	111

It was agreed that the convention was a decided success from all points of view, including interest and coöperation.

In Memoriam

GEORGE A. HAMILTON

THE death, on January 10, 1935, of George Anson Hamilton, at the age of 91 years, removed from the membership one of the few individuals who had been actively interested in Institute affairs throughout its entire life.

Mr. Hamilton, a Charter Member, one of the first vice presidents (1884–86), and national treasurer 1895–1930, was transferred to the grade of Fellow in 1913, and was elected an Honorary Member in 1933. He was a member of the first editing committee, the committee on permanent quarters, and several other Institute committees.

RESOLVED: That the board of directors of the American Institute of Electrical Engineers hereby expresses, upon behalf of the membership, its keen regret at the death of Mr. Hamilton, and its sincere appreciation of his many contributions to the development of the activities of the Institute, and be it further

RESOLVED: That these resolutions be entered in the minutes and copies be transmitted to members of his family.

—A.I.E.E. Board of Directors, January 21, 1935

Members Warned Against Employment Exploitation

Information considered to be of some general importance to the membership of the Institute has been brought to the attention of headquarters by members of the Institute who have had experiences with some commercial employment "services," or who have had occasion to investigate the operating practices and procedure of such "services." A typical case investigated and recently reported to Institute headquarters is one currently advertising in industrial and trade magazines. These advertisements by statement and inference purport to show a peculiar ability to serve technical and professional men and executives in the higher income brackets.

A personal investigation of this typical agency led to a report that can be summarized as follows:

1. The client is required to pay a substantial advance fee and is required to pay for all postage on all ensuing correspondence or circularization; in short, is required to assume all liability.

2. The agency then prepares a list or lists of names to be circularized; the responsibility for checking and approving these lists resting on the clients. A typical set of lists checked by the reporting investigator gave every indication of having been compiled from obsolete directories, and was full of duplications and other errors.

3. The agency prepares a circular letter mentioning the qualifications of the applicant; the letters investigated were purely circular in form and appearance, with the exception of the addressee's name typed in at the top. In a typical case, no replies other than one or two mere acknowledgments were received, although several hundred letters were mailed out at the expense of the client.

4. A personal visit to the agency's offices indicated that, in spite of high sounding names and impressive stationery, the so-called personal advertising service was nothing but a desk-space proposition carried on as an adjunct to a very ordinary employment bureau.

5. There was every evidence that the methods used were such that the possibility of a client securing employment such as described would be remote even in boom times and practically impossible under any other circumstances.

Members considering the services of commercial employment agencies are urged to be skeptical, and to make a thoroughgoing personal investigation before spending any money. There are no doubt many reputable employment agencies capable of serving professional and technical men, but there are certainly many times that number, who are interested only in providing themselves with dividends. Even in the case of agencies having on file actual employment openings, and consequently able to refer clients to direct correspondence or contact with employers definitely seeking professional services, the question of advance payment should be considered carefully.

Capable and experienced persons long associated with professional personnel placement are strong in the opinion that best results are obtained through a personal contact campaign carried on directly by the individual seeking employment, and that second place goes to a correspondence

campaign likewise carried on directly by the person seeking employment. The person seeking employment is in the best position to know where he could apply himself most effectively, and has available through libraries or usually otherwise can obtain up-to-date trade and commercial directories that will help him in remote localities with which he may be personally unfamiliar.

In an effort to serve those who may be seeking employment, ELECTRICAL ENGINEERING has republished an article "Finding Work" in the news section of the December 1934 and January 1935 issues. This article was prepared by a recognized authority and offers many pertinent suggestions.

E.E. Fellowships in Sweden Offered

A number of travelling fellowships for study in the Scandinavian countries during the academic year 1935–36 will be awarded by The American-Scandinavian Foundation to students of American birth. These fellowships, as in previous years, will carry stipends of $1,000 each. Among these fellowships is the Irving Langmuir fellowship in electrical engineering, for research in electrical engineering in Sweden. Instructors and graduate students in electrical engineering are especially invited to apply for this fellowship, which will be awarded through the usual routine followed by the Foundation.

The jury which makes the final selection for the Foundation will meet in April and nominations must therefore be in the hands of the Foundation on or before March 15, 1935. All requests for information should be addressed to Neilson Abeel, secretary of The American-Scandinavian Foundation, 116 East 64th Street, New York, N. Y.

Prominent Engineering Educator Dies. Palmer C. Ricketts, president and director of Rensselaer Polytechnic Institute, Troy, N. Y., died at Johns Hopkins Hospital, Baltimore, Md., December 10, 1934. Doctor Ricketts was 78 years of age, had been a member of the Rensselaer faculty since his graduation there in 1875, and for the past 42 years has been the active head of the institution. Doctor Ricketts was an honorary member of the American Society of Civil Engineers, a member of The American Society of Mechanical Engineers, and the American Institute of Mining and Metallurgical Engineers, as well as the Institution of Civil Engineers of Great Britain.

J. F. Kelly, Association Executive, Dies. John Frederick Kelly, managing director of the Association of Iron and Steel Electrical Engineers, and editor of the *Iron and Steel Engineer*, died November 16, 1934. Mr. Kelly was one of the best known figures in the iron and steel industry and had long been active in advancing the interests of electrical engineers in this industry, and in encouraging the application of electrical methods. He was born in McKeesport, Pa., November 25, 1880. After being connected with various steel mills in the Pittsburgh district, he became associated with the Westinghouse Electric and Manufacturing Company, where he was employed in the office of the manager of works. In 1909 he left the Westinghouse company to go to the electrical department of the National Tube Company at McKeesport. In 1917 he was elected national secretary of the Association of Iron and Steel Electrical Engineers, leaving the National Tube Company in 1918 to establish the A.I. and S.E.E. offices in Pittsburgh. He was later made managing director of the association and editor of the *Iron and Steel Engineer*.

Faraday Medal Awarded Dr. F. B. Jewett

The council of the Institution of Electrical Engineers (of Great Britain) unanimously awarded its Faraday Medal for 1935 to Dr. Frank B. Jewett (A'03, M'10, F'12, and past-president), vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., New York, N. Y. The action was taken at a meeting of the council on January 24, 1935.

The Faraday Medal of the Institution of Electrical Engineers is a bronze medal awarded not more frequently than once a year either for notable scientific or industrial achievement in electrical engineering, or for conspicuous services rendered to the advancement of electrical science, without restriction as regards nationality, country of residence, or membership of the Institution.

The first Faraday Medal was awarded to Oliver Heaviside (HM'18) in 1922. Other members of the A.I.E.E. who have received the Faraday Medal are S. Z. de Ferranti (A'03, M'06, HM'12) 1924; Elihu Thomson (A'84, M'91, F'13, HM'28, member for life and past president) 1927; Guido Semenza (A'02) 1929; Charles H. Merz (A'95, M'10, F'13 and member for life) 1931; and Dr. F. B. Jewett (A'03, M'10, F'12, and past president). Of these, Doctor Thomson, Mr. Merz, and Doctor Jewett are now living.

A brief biographical sketch of Doctor Jewett's career appears in ELECTRICAL ENGINEERING for January 1935, page 140, in connection with his election to honorary membership in the Institute of Electrical Engineers of Japan (the "Denki-Gakkwai"). Doctor Jewett joined the Institution of Electrical Engineers in 1922 with the grade of "member."

1935 Pacific Coast Convention Transferred to Seattle

Instead of being held in Los Angeles, Calif., as previously announced, the Institute's 23d Pacific Coast convention will be held in Seattle, Wash., under the sponsorship of the Institute's Seattle Section, according to telegraphic information received just as this issue was going to press. According to Vice Presidents R. W. Sorensen of Pasadena, Calif., and F. O. McMillan of Corvallis, Ore., the exchange has been effected incident to the fact that the Institute's 51st annual summer convention will be held in Los Angeles or the immediate vicinity in June 1936, and it is expected that the 1936 Pacific Coast convention will be consolidated with it.

Oklahoma City District Meeting Plans Under Way

The annual meeting of the Institute's South West District (number 7) will be held at Oklahoma City, Okla., on April 24–26, 1935, with headquarters at the Skirvin Hotel. Four technical sessions are planned for this meeting in addition to the Student session. Papers will be presented by several engineers of national reputation; these papers will deal with various phases of electrical distribution, telephone communication, insulation coördination, and engineering education.

Those in attendance at the sessions will hear presented the facts and problems in power distribution system regulation and investment, and in turn will hear discussed modern means for improved voltage regulation at minimum investment per kilowatt-hour. Modern trends in metering design and application will be covered. The questions as to why definite insulation levels have been recommended for transformer insulation, and why various types of insulation and impulse levels have been utilized for transmission lines will be answered. Results obtained from applying these insulation levels to transmission lines will be reviewed.

Those attending the sessions also will hear numerous features of telephone communication technique and application discussed, including details of telephone protective devices and the application of telephone equipment to the power industry. A general discussion of modern trends in engineering education and the colleges' adaptation to these trends also will be presented.

The program also includes an inspection trip and a banquet. A special entertainment is being arranged by the committee for the ladies at the Oklahoma City Golf and Country Club.

Oklahoma City is situated almost at the center of the area composing District 7 of

the A.I.E.E., and is favored with splendid transportation facilities radiating in all directions. The city has a population of approximately 200,000; it entertains over 350 conventions each year and possesses excellent sports and amusement facilities, including 12 all-year golf courses.

Complete details of the arrangements for this district meeting are scheduled to appear in the March 1935 issue of ELECTRICAL ENGINEERING. The general committee in charge of the meeting consists of the following:

F. J. Meyer, vice president, District 7; C. W. Mier, secretary, District 7; A. C. Bookout, chairman, entertainment and arrangements committee; R. F. Danner, chairman, papers committee; W. A. Kitchen, chairman, attendance and publicity committee; A. Naeter, chairman, Oklahoma City Section; C. E. Bathe, secretary, Oklahoma City Section; E. B. Jennings, chairman, reception and registration committee; and E. D. Freeman, chairman, transportation and trips committee.

Joint Meeting Held by Alabama Branch and Section

The University of Alabama Branch and the Alabama Section of the A.I.E.E. held a joint meeting on the University's homecoming day, November 10, 1934. The object of this meeting, at which social and entertainment features rather than technical features were stressed, was to attempt to repay the courtesies and interest shown in this Branch in the past by the Alabama Section of the Institute. As a secondary objective, it was desired that the members of the Alabama Section become more thoroughly acquainted with the members of the student Branch and their activities.

The following members of the Alabama Section were present:

H. J. Scholz, chairman

W. D. Ketchum, member of the student activities committee

W. W. Ballew, past chairman

H. M. Woodward, secretary

B. B. Bessesen, member of the Alabama Section and superintendent of power of T.V.A.

Others attending were E. B. Thornton, illuminating engineer, D. D. Wendell, district engineer of the Alabama Power Company, and Prof. L. H. Fox of Mississippi State College.

The program for the day included the review of the R.O.T.C. in honor of Major-General Moseley, commander of the Fourth Corps Area; joint meeting of the A.I.E.E. in the engineering library; the football game between the University of Alabama and Clemson College; and the Athletic Club dance.

While the men inspected the electrical engineering laboratories, the women guests were conducted on a sightseeing tour of the campus and buildings by Mrs. Fred Maxwell, wife of the student counselor.

At the joint meeting, Mr. Scholz and Mr. Bessesen made 2 interesting talks. Mr. Scholz spoke on the benefits of the A.I.E.E. organization, both in college and in the profession; he emphasized the need for continuation of contact with the Institute after graduation. Mr. Bessesen gave a vital talk in connection with the choice of engineering as a profession. It was felt that the meeting was a success in every respect, affording not only valuable contact, but assisting the student to close the mental gap between college work and later professional work.

A.S.M.E. Names New National Secretary

The council of The American Society of Mechanical Engineers has appointed Clarence E. Davies national secretary of that Society. He succeeds the late Dr. Calvin W. Rice (A'97, F'12) who died October 2, 1934. (A biographical sketch of Doctor Rice's career was given in ELECTRICAL ENGINEERING for November 1934, page 1557–8.)

The new national secretary, Mr. Davies, has served on the staff of the A.S.M.E. for nearly 15 years, and his natural ability coupled with the training which he has received during this period, admirably fit him for his new position. He graduated from Rensselaer Polytechnic Institute, Troy, N. Y., in 1914, and then entered the production department of the Remington Typewriter Company. During the war he served in the ordnance department of the U. S. Army and was assigned to the Frankford Arsenal on the manufacture of artillery, ammunition, and fuses. He now holds the rank of lieutenant colonel in the Ordnance Reserve Corps and participates actively in the organization and operation of the New York Ordnance District.

C. E. DAVIES

Colonel Davies first became connected with the headquarters staff of the A.S.M.E. in 1920, when he was appointed associate editor, and has continued without interruption since that date. In 1921 he was appointed managing editor and assistant secretary, and in 1931 was appointed executive secretary, in charge of the administration of the headquarters office. With his recent appointment as national secretary, the offices of secretary and executive secretary are combined.

Colonel Davies has been active in the Engineers' Council for Professional Development, and in 1934 was made its first secretary. He is honorary corresponding secretary for North America of the Newcomen Society (England) for the study of the history of engineers.

Columbia University Offers E. E. Scholarships

The governing bodies of Columbia University have placed at the disposal of the A.I.E.E. each year, a scholarship in electrical engineering in the school of engineering of Columbia University for each class. The scholarship pays $350 toward the annual tuition fees which vary from $340 to $360, according to the details of the course selected. Reappointment of the student to the scholarship for the completion of his course is conditioned upon the maintenance of a good standing in his work.

To be eligible for the scholarship, the candidate recommended will have to meet the regular admission requirements, in regard to which full information will be sent without charge upon application to the secretary of the University or to the national secretary of the Institute, 33 West 39th St., New York, N. Y.

In a letter addressed to the national secretary of the Institute, an applicant for this scholarship should set forth his qualifications (age, place of birth, education, reference to any other activities, such as athletics or working way through college, references, and photograph). A committee composed of W. I. Slichter, *chairman*, Francis Blossom, and H. C. Carpenter will consider the applications and will notify the authorities of Columbia University of their selection of a candidate. The last day for filing of applications for the year 1935–36 will be June 1, 1935.

The course at the Columbia school of engineering is a graduate course which may be either elective leading to the degree of master of science or prescribed leading to the degree of electrical engineer. For the former, requirement for admission is the completion of a 4 year course in electrical engineering as evidenced by a bachelor's degree from an approved institution. For the professional degree, the requirements are more specific as to course content and include a considerable proficiency in mathematics, physics, and chemistry, and some knowledge of the humanities, as well as the usual undergraduate technical courses. The candidate is admitted on the basis of his previous collegiate record without undergoing special examinations. Other qualifications being equal, members of the student Branches of the A.I.E.E. will be given preference.

The purpose of this advanced course is to produce a high type of engineer, trained in the humanities as well as in the fundamentals of his profession. It is hoped that Enrolled Students and others qualified will show a keen interest in this scholarship.

F. L. Stuart, Prominent Railroad Engineer, Dies. Francis Lee Stuart, former chief engineer of the Erie, and Baltimore and Ohio railroads, and past president of the American Society of Civil Engineers, died at Essex Fells, N. H., January 15, 1935. Mr. Stuart, born at Camden, S. C. in 1866, became a rodman on the B. & O. Railroad immediately upon graduation from college. Subsequently he progressed through many phases of railroad work. In 1897 Mr. Stuart was in charge of hydrographic sur-

veys for the Nicaragua Canal Commission; and later, as division engineer for the Isthmian Canal Commission he was on canal work until 1899 when he returned to the B. & O. In 1905 he became chief engineer of the Erie Railroad, and in 1910 chief engineer of the B. & O. Since 1915, he had been in private practice, except during the war, when he served on the War Industries Board and with the U. S. Railroad administration.

Engineers' Liabilities Under the Securities Act

Under the Securities Act of 1933 as amended by Title II of the Securities Exchange Act of 1934, grave responsibility is placed on the engineer in connection with reports that may be made concerning projects against which securities are to be issued, and severe penalties are provided for dereliction of duty. Thus, every engineer who undertakes to supply any portion of the facts upon which an issue of securities may be based, should realize fully the responsibility that he assumes thereby under the Securities Act and the nature of the penalty to which he subjects himself for inaccurate, incomplete, or unwarranted statements.

In the January 1935 issue of *Civil Engineering*, the American Society of Civil Engineers published a "Digest of the Securities Act of 1933 as Affecting Engineers" and "Comment on Act as Applied to Engineers" prepared by W. W. Colpitts, member of that society and consulting engineer of New York, N. Y. The society has announced the availability of 14-page 6 x 9 inch pamphlet reprints of the article at A.S.C.E. headquarters, 29 West 39th Street, New York, N. Y., at 25¢ per single copy, or at 15¢ per copy in lots of 100.

E.C.P.D. Reports Substantial Progress During 1934

Engineers' Council for Professional Development, which was founded in 1932 as an agency of the united engineering profession to enhance the status of the engineer, has completed the second year of its work. In entering upon its third year various phases of its program are being carried on with renewed activity.

Particularly significant at this time to members of the Institute is the approval given by the Institute's board of directors in a resolution adopted January 21, 1935, giving approval to the plan of accrediting engineering schools proposed by the E.C.P.D. committee on engineering schools. This resolution is as follows:

Be It Resolved

First: That this board hereby consents to the plan of accrediting engineering schools proposed by E.C.P.D. in its communication of November 19, 1934.

Second: That it is the desire and hope of this board that a simpler and less costly plan of accrediting engineering schools may be found possible after trial of and experience with the proposed plan.

Third: That a copy of this resolution be transmitted to E.C.P.D. and to each of this Institute's representatives thereon.

The procedure for developing a list of accredited schools by this committee has advanced through the experimental stage, and it is expected that early in 1935 active steps will be taken to carry on this accrediting.

In addition to the Institute, the following societies have approved the E.C.P.D. as the accrediting agency for engineering schools: The American Society of Mechanical Engineers, American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners. Special arrangements for accrediting curricula in chemical engineering have been arranged with the Institute of Chemical Engineers.

The work of the committee during the past year falls into 2 general divisions: (1) The revision of the questionnaire to be used in the accrediting program; and (2) the study and recommendation of a method of procedure and form of organization for carrying out the actual work of such accrediting. The plan recommended is essentially as follows:

1. The committee on engineering schools shall be the operating organization in the accrediting process.
2. The inspection of the schools shall be performed by committees of competent individuals, designated as "delegatory committees" representing and nominated by the committee on engineering schools.
3. The names of those so nominated shall be submitted to the constituent societies for their approval of the persons who represent their particular field of engineering.
4. The schools shall be inspected on a regional basis, the country being divided into approximately 7 regions. For each region the delegatory committee shall consist of 5 members and 3 alternates living in or near the region. At least one member of each delegatory committee shall be an engineer not on the staff of an engineering school.

The program of actually doing the accrediting involves 2 procedures, as follows:

1. The filling out by officers of the school of a questionnaire covering factual information on the curricula to be accredited, and on the school and faculty involved.
2. An inspection by the delegatory committee.

The delegatory committee will report to the committee on engineering schools which in turn will report to the council of the E.C.P.D., whose action shall be final. The expense of visits of inspection will be met by standardized charges against the schools whose curricula are involved.

Activities of the 3 Other Committees

Two phases of the work of the E.C.P.D. will require the coöperation and enthusiasm of engineers throughout the country. The first of these phases is that dealing with the selection and guidance of the young men in a secondary school who are interested in entering engineering school and who wish to follow an engineering career. The sections of the engineering societies of the country are being requested to organize local committees and to make contact with the authorities in the secondary schools so that the advice and guidance of the engineers in the community will be made available to aid young men who wish to enter the engineering field. The procedures for this work are being developed by the committee on student selection and guidance.

The second phase of the program in which engineers of the country are concerned is that dealing with the stimulation and development of the younger engineer to obtain the standing of the full-fledged engineer. This work is being carried on by the committee on professional training. This committee has developed a pamphlet of suggestions for junior engineers which may be secured at 10 cents per copy from the E.C.P.D., 29 West 39th Street, New York, N. Y. This pamphlet contains a scheme of self-appraisal and a reading list for junior engineers which includes selected titles on natural science, philosophy, economics, sociology, psychology, business and industrial management, literature, history, biography, travel, and fine arts. (Sections of this list are appearing whenever space permits in the news section of Electrical Engineering, starting with the December 1934 issue.)

The committee on professional recognition is at work correlating the various grades of membership with the requirements for licensing of engineers, and it is expected that during the coming year there will be developed a plan which will simplify considerably the detail work of this problem.

Officers, Representatives, and Committee Members

At the second annual meeting of the E.C.P.D. held in the Engineering Societies Building, New York, N. Y., October 23, 1934, the chairman of the E.C.P.D. and chairmen of the 4 standing committees were reëlected. At this meeting, an information committee was established under the chairmanship of H. C. Parmelee, vice president of the McGraw-Hill Publication Company, New York, N. Y. Officers of the E.C.P.D., representatives of the participating societies, and the members of the standing committees are as follows:

Executive Committee

Dr. C. F. Hirshfeld (A'05), *chairman*, chief research engineer, Detroit (Mich.) Edison Company, Detroit.

G. T. Seabury, *secretary*, secretary, A.S.C.E., New York, N. Y.

J. Vipond Davies, (A.S.C.E.), consulting engineer, New York, N. Y.

Dr. F. M. Becket (A.I.M.E.), vice president, Electro Metallurgical Company, New York, N. Y.

Dr. W. E. Wickenden (A'07, M'13) (A.S.M.E.), president, Case School of Applied Science, Cleveland, Ohio.

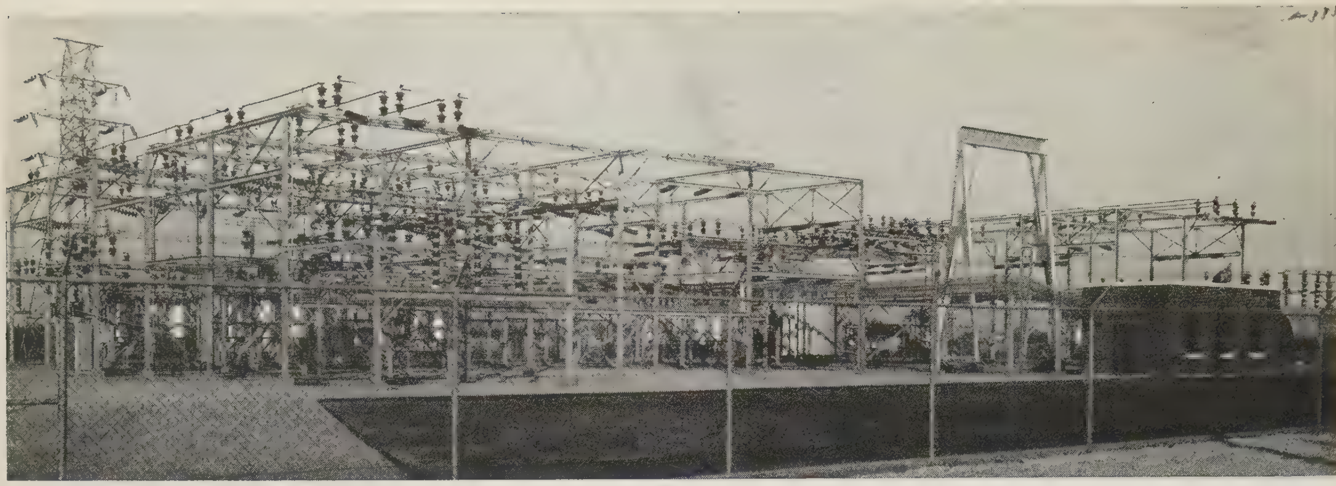
Dr. C. F. Scott (A'92, M'93, F'25, HM'29, member for life and past-president) (A.I.E.E.), professor of electrical engineering emeritus, Sheffield Scientific School, Yale University, New Haven, Conn.

Dr. H. C. Parmelee (A.I.Ch.E.), vice president, McGraw-Hill Publishing Company, New York, N. Y.

Gen. R. I. Rees (S.P.E.E.), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.

Dr. D. B. Steinman (N.C.S.B.E.E.), president, National Council of State Boards of Engineering

A Substation Near Oklahoma City, Scene of a Forthcoming A.I.E.E. Meeting



A VIEW of the Reno Street 66 kv switching and regulating substation of the Oklahoma Gas and Electric Company is shown here; it is one of the points which will be inspected by those attending the A.I.E.E. South West District meeting in Oklahoma City, April 24–26, 1935. This substation is located just east of the city and adjacent to the Oklahoma City oil fields. A 60,000 kva, 10 per cent buck and boost voltage regulator, equipped for automatic control, is located in the station.

Examiners, and consulting engineer, New York, N. Y.

Representatives of the A.S.C.E.

J. Vipond Davies (1935), consulting engineer, New York, N. Y.
H. P. Eddy (1936), Metcalf and Eddy, Boston, Mass.
J. P. H. Perry (1937), vice president, Turner Construction Company, New York, N. Y.

Representatives of the A.I.M.E.

D. F. Irvin (1935), Oliver United Filters, Inc., New York, N. Y.
B. F. Tillson (1936), consulting engineer, Montclair, N. J.
Dr. F. M. Becket (1937), vice president, Electro Metallurgical Company, New York, N. Y.

Representatives of the A.S.M.E.

Dr. W. E. Wickenden (A'07, M'13) (1935), president, Case School of Applied Science, Cleveland, Ohio.
Dr. C. F. Hirshfeld (A'05) (1936), chief research engineer, Detroit (Mich.) Edison Company.
To be appointed (1937).

Representatives of the A.I.E.E.

Dr. C. F. Scott (A'92, M'93, F'25, HM'29, member for life and past-president) professor of electrical engineering emeritus, Sheffield Scientific School, Yale University, New Haven, Conn.
L. W. W. Morrow (A'15, F'25 and director) (1936), editor, *Electrical World*, New York, N. Y.
C. O. Bickelhaupt (M'22, F'28) (1937), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.

Representatives of the S.P.E.E.

Dr. D. C. Jackson (A'87, M'90, F'12, member for life, and past-president) (1935), professor of electrical engineering, Massachusetts Institute of Technology, Cambridge.
Gen. R. I. Rees (1936), assistant vice president, American Telephone and Telegraph Company, New York, N. Y.
H. P. Hammond (1937), professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.

Representatives of the A.I.Ch.E.

J. M. Weiss (1935), president, Weiss and Downs, New York, N. Y.
Dr. H. C. Parmelee (1936), vice president, McGraw-Hill Publishing Company, New York, N. Y.
A. B. Newman (1937), professor of chemical engineering, Cooper Union, New York, N. Y.

Representatives of the N.C.S.B.E.E.

T. Keith Legare (1935), secretary, N.C.S.B.E.E., Columbia, S. C.
Dr. D. B. Steinman (1936), consulting engineer, New York, N. Y.
P. H. Daggett (A'08) (1937), dean, college of engineering, Rutgers University, New Brunswick, N. J.

Committee on Student Selection and Guidance

R. L. Sackett (1936), *chairman*, dean of college of engineering, Pennsylvania State College, State College.
O. J. Ferguson (A'05, F'13) (1935), dean, college of engineering, University of Nebraska, Lincoln.
W. B. Plank (1935), professor of mining engineering, Lafayette College, Easton, Pa.
H. N. Davis (1936), president, Stevens Institute of Technology, Hoboken, N. J.
T. Keith Legare (1936), secretary, N.C.S.B.E.E., Columbia, S. C.
R. H. Jacobs (1937), Englewood, N. J.
V. M. Palmer (1937), industrial economy engineer, Eastman Kodak Company, Rochester, N. Y.

Committee on Professional Training

Gen. R. I. Rees (1936), *chairman*, assistant vice president, American Telephone and Telegraph Company, New York, N. Y.
R. A. Seaton (1935), dean, director of engineering, Kansas State College, Manhattan.
W. B. Updegraff (1935), vice president, Watson Stillman Company, New York, N. Y.
D. S. Kimball (1936), dean, college of engineering, Cornell University, Ithaca, N. Y.
A. D. Smith, Jr. (1936), president, George W. Smith Woodworking Company, Philadelphia, Pa.
A. R. Stevenson (A'20) (1937), engineering general department, General Electric Company, Schenectady, N. Y.
A. B. Newman (1937), professor of chemical engineering, Cooper Union, New York, N. Y.

Committee on Engineering Schools

K. T. Compton (F'31) (1936), *chairman*, Massachusetts Institute of Technology, Cambridge, Mass.
H. A. Curtis (1935), director of research and development, Vacuum Oil Company, Paulsboro, N. J.
A. A. Potter (1935), dean, Purdue University, Lafayette, Ind.
P. H. Daggett (A'08) (1936), dean, college of engineering, Rutgers University, New Brunswick, N. J.
H. P. Hammond (1936), professor of civil engineering, Polytechnic Institute of Brooklyn, Brooklyn, N. Y.
G. M. Butler (1937), dean, college of mines and engineering, director, Arizona Bureau of Mines, University of Arizona, Tucson.
I. C. Crawford (1937), state engineer, public works administration, University of Idaho, Moscow.

Committee on Professional Recognition

C. N. Lauer (1935), *chairman*, president, Philadelphia Gas Works, Pa.
J. P. H. Perry (1935), vice president, Turner Construction Company, New York, N. Y.
J. W. Barker (M'26, F'30) (1936), dean, school of engineering, Columbia University, New York, N. Y.
H. C. Parmelee (1936), vice president, McGraw-Hill Publishing Company, New York, N. Y.
Dr. D. B. Steinman (1936), consulting engineer, New York, N. Y.
Dr. F. M. Becket (1937), vice president, Electro Metallurgical Company, New York, N. Y.
F. L. Bishop (1937), secretary, S.P.E.E., University of Pittsburgh, Pa. (H. S. Rogers, alternate for Professor Bishop.)

Illumination Commission to Meet in Germany

The 1935 session of the International Commission on Illumination will be held in Berlin, July 2–9, according to an announcement by the United States national committee.

The committee, which held its annual meeting in New York, N. Y., November 9, 1934, includes among its membership representatives from the American Institute of Electrical Engineers, the Illuminating Engineering Society, the Optical Society of America, American Physical Society, and the Bureau of Standards. E. C. Crittenden (A'19, M'22) and G. H. Stickney (A'04, F'24) were reëlected respectively to the offices of president and secretary-treasurer of the United States committee, as well as being reappointed United States members of the international executive committee, of which body Dr. C. H. Sharp (A'03, F'12, and member for life), vice president, is also a member.

The United States committee reviewed the reports of its representatives on the 27 technical committees and made plans for participation in the Berlin meetings. The United States secretariats manage 3 of these technical committees, namely: factory and school lighting, aircraft lighting, and lighting education. In factory and school lighting, world-wide statistical surveys are being made on conservation of eyesight, special attention being given to the welfare of school children with defective vision. Because of the international character of aerial navigation, important standards for lighted signals are being set while the practices are still flexible. An English-French-German vocabulary of special terms is being established.

The commission is coöperating with the International Committee on Weights and Measures, an organization established under international treaty to which this country is a party. Progress is well under way to the establishment of a primary standard of light and toward the elimination of certain discrepancies in light measurement, which have proved embarrassing. The accurate measurement of the new gaseous tube electric illuminants, which is becoming more and more important is also engaging scientific attention.

These and many other vital questions are scheduled for discussion in Berlin, not the least of which are street and automobile lighting, in connection with which considerable differences of opinion exist in various countries.

The national committee is endeavoring to secure a large attendance of American experts in order to insure an adequate expression of the viewpoints prevailing in this country.

American Engineering Council

A.E.C. Holds Annual Meeting in Washington

THE annual meeting of American Engineering Council was held at the Mayflower Hotel in Washington, D. C., January 10–12, 1935, the main points stressed being the coöperation of engineers in the broad work program being planned by the federal government, and the better coördination of the existing system of engineering societies throughout the country. Membership in American Engineering Council, which may be termed the "Washington Embassy" of engineers, specifically includes 7 national, 4 state, and 11 local engineering societies. Delegates from these and other societies were present at the annual meeting.

Principal features of the annual meeting were sessions at which prominent federal officials described the engineering features of the recovery program; a conference of the secretaries of national, state, and local engineering societies; a "good fellowship" dinner; and the election of officers.

Resolutions Adopted

Action before the executive, public affairs, and other committees of Council led to the adoption of the following resolutions by the assembly:

1. New membership plan. A flat rate plan of nominal dues for local societies with delegates to Council meetings paying their own expenses; division of the country into 9 districts so that a group of societies in any district may jointly send a delegate to meetings at the expense of Council. Delegates from individual societies under such a joint plan may attend at the expense of their own societies. (Adoption of the plan automatically brings into Council the Engineers' Club of Philadelphia and the Engineering Societies of New England which voted previously to join contingent upon the plan's acceptance. At least a dozen other societies have announced their intention of joining.)

2. Division of the public affairs committee into subcommittees, the chairmen of which are to be members of the main body and are to coördinate with similar committees of the engineering societies toward joint action upon common objectives.

3. A public affairs committee to be set up in each state, members to be key men from local sections and societies, to provide a network of organization for deliberation and action upon public matters of moment to the profession.

4. Continue support of the national mapping program.

5. On motion of Robert McCuen, who pointed out that rural electrification work is scattered through several federal agencies, to pool facts in this field under the U. S. Bureau of Agricultural Engineering, assembling data already collected by engineering groups throughout the country.

6. To continue the conference of secretaries from time to time.

7. Flood control committee considered 3 bills before the past Congress, advocating that they be opposed, should they come up again. The bills had to do with development of the Arkansas River and tributaries. Development was considered too large a job to be undertaken as a single project. T.V.A. type of operation was thought too new an experiment to be extended until it has proved itself. The projects require further study as to feasibility, it was stated.

8. Ralph E. Flanders turned over an A.S.M.E. report on machine hour limitation requesting that A.E.C. present it before the forthcoming production hearing of N.R.A.

9. At request of Los Angeles and San Francisco sections of A.S.C.E., to support continued seismological studies of the U.S. Coast and Geodetic Survey to provide basic data regarding earthquakes.

10. Continue efforts to have old canal, at Great Falls on the Potomac near Washington, D. C., be made a memorial to George Washington, the engineer, who laid out the work.

11. Coöperate with other agencies including Purdue Research Foundation, National Bureau for Economic Research, and Board of Surveys and Maps of the Federal Government.

12. (Disfavored) The committee on uniform classification of engineers in telephone directories was discharged with thanks and its report not accepted.

Another important step was the increasing of the 1935 budget of Council $^1/_3$ over last year, thus enabling Council to render more effective service. (The Institute's 1934–35 appropriation for Council is $9,000, compared with an appropriation of $7,625 for 1933–34, and an average appropriation of $16,227 per year for the 5 year period ending September 30, 1933.

Engineering Features of Recovery Program

Because of the importance of the federal program in terms of engineering development, the principal focus of discussions was toward an interchange of ideas and information between the delegates and federal officials in responsible charge of construction, planning, and other engineering functions of the government. In effect, the meeting resulted in a symposium of the recovery program.

The executive committee of American Engineering Council, photographed during the recent annual meeting held in Washington, D. C., January 10–12, 1935. All members of executive committee were present with the exception of Dr. William McClellan who was unable to be present. In the back row are, left to right: C. O. Bickelhaupt, vice president; W. H. Woodbury, vice president; and Col. Paul Doty, vice president. In the front row, left to right are: C. E. Stephens, treasurer; F. M. Feiker, executive secretary; J. F. Coleman, president; and A. J. Hammond, vice president

R. E. Flanders, President of the A.S.M.E., led the discussion on the outlook for durable goods industries. Wm. P. Witherow, vice-chairman, Industrial Advisory Board, N.R.A., spoke at a luncheon meeting, January 11. Confusion in N.R.A. objectives has disappeared, he declared. N.R.A. is opposed to restrictive provisions in codes and the Administration is positively in favor of the profit system. Industry, he asserted, favors minimum wage provisions.

R. E. W. Harrison, chief of the machinery division, U. S. Bureau of Foreign and Domestic Commerce, stressed the increasing of efficiency in railroad and merchant marine equipment as one of the steps toward recovery of the durable goods industry. The importance of P.W.A. to this industry, he said, cannot be overemphasized. Modernization of navy yards, he stated, is resulting in the replacement of machinery in use 25 to 30 years while machine efficiency has trebled. Engineers should do more to encourage the development of patents, in Mr. Harrison's opinion. The volume of new patents, he said, has followed the downward trend of the business cycle.

The session on planning and natural resources development was led by G. W. McCuen, president of the American Society of Agricultural Engineers. Dr. H. S. Person, acting director, water resources section, National Resources Board, described the general concept of planning as it has grown under the stimulus of the several new federal agencies entering this field. Engineers may enter the planning movement, he said, as members of planning boards or technical advisory committees to such boards, and may share in the resultant design and construction. He advocated the setting up of functional committees under the professional societies to develop data and technical standards for planning.

Dr. Isador Lubin, director of the U. S. Bureau of Labor Statistics, describing progress on the survey of the engineering profession which his organization is about to make in coöperation with Council and engineering societies throughout the country. More than 100,000 questionnaire schedules will be mailed, he said, urging engineering societies to use all means at their disposal to insure prompt and accurate returns.

The survey and mapping program of the federal government was discussed by Capt. R. S. Patton, director, U. S. Coast and Geodetic Survey, who pointed out that only $^1/_2$ the nation has been mapped and only $^1/_4$ adequately mapped. Captain Patton told of the C.W.A. work under his organization which employed 10,000 men last winter, most of whom were engineers, and has continued on a smaller scale under state relief administrators. The National Resources Board has reported to the president a $117,000,000 plan for completion of the map of the United States in 10 years employing 7,500 to 10,000 men, half of whom will be engineers, Captain Patton said.

The Administration's agricultural policy was explained by M. L. Wilson, Assistant Secretary of Agriculture, who spoke in executive session.

M. S. Eccles, Governor of the Federal Reserve Board, gave a most illuminating talk on the coördination of private and governmental expenditures toward the common objective of recovery.

Led by A. J. Hammond, vice president of A.E.C. and past-president of the A.S.C.E. and the Construction League of America, construction trends were discussed in their federal, private, and relief aspects. Mr. Hammond stated that, with a $^4/_5$ drop in the construction industry during the depression, the construction worker is the real forgotten man.

Col. D. H. Sawyer, director of the Federal Employment Stabilization Office, and former P.W.A. administrator, spoke on private construction, saying that the spirit of salesmanship must be revived in the industry without so much leaning upon the federal government. The creative spirit still exists among engineers, he said, and these are the men who must devise projects, prove their feasibility, and sell them to bankers and industrialists if the construction industry is to move forward once more.

Thomas Hibben, chief engineer of the F.E.R.A., told of the development of work relief along lines of engineering construction with the 2-fold purpose of turning out socially useful work and enabling skilled men to retain their skill and their self-respect. Thousands of engineers have served in supervisory phases of the program.

Clarence McDonough, chief of the engineering division, P.W.A., stressed the importance of the National Resources Board findings in future development; he made no predictions as to the future of P.W.A. while the president's new work program is yet pending.

C. C. Anthony, industrial adviser, Federal Housing Administration, urged engineers to get behind the housing program and to keep posted on its progress. Engineers and architects, he said, can find active work in the modernization program as well as in new construction.

Good Fellowship Dinner

The A.E.C. dinner, preceded by an "hour of good fellowship," proved to be the largest engineering function ever held in Washington. More than 400 attended. Governor Eccles of the Federal Reserve Board was the guest of honor. William McClellan, chairman of Council's finance committee, was toastmaster. The 4 presidents of national engineering societies in attendance and the chairman of the secretaries' conference made short addresses pledging their support to Council's program for the coming year.

The principal speaker was Dr. Harold G. Moulton, president of the Brookings Institution, which research organization has been making a detailed study of economic trends over the past 30 years. Underconsumption rather than overcapacity was indicated by Doctor Moulton's charts. In the boom years, capacity in most industries did not run far ahead of the demand for goods and services.

Conference of Secretaries

A conference of some 40 secretaries of engineering societies, national, state, and local, was held during the first day and a half of the A.E.C. sessions under the chairmanship of C. E. Sabin, secretary of the Cleveland Engineering Society. This was the largest meeting of its kind yet held. The first secretaries' conference met in 1923 with the A.E.C. meeting at Washington of that year and the group assembled in other cities biennially thereafter until 1929, lapsing until this year.

A committee on coördination of engineering organizations was set up by the conference to study the problem of overlapping dues and more effective joint action of the scattered societies. Representatives of 2 national, 1 state, and 2 local societies are on the committee under the chairmanship of O. L. Angevine, secretary of the Rochester Engineering Society. A progress report is to be rendered at the next conference tentatively set for June 1936, in Pittsburgh, Pa., under the chairmanship of K. F. Treshow, secretary of the Engineers Society of Western Pennsylvania.

Opening Thursday morning, January 10, the conference heard an address of welcome by J. F. Coleman, president of A.E.C. Frederick M. Feiker, executive secretary of A.E.C., presented charts as to the distribution of engineers and engineering societies geographically throughout the country, giving strong evidence of the need for coördination. The conference then discussed the problems of society management, topic by topic, exchanging ideas as to successful methods.

A review of relief activities was led by G. T. Seabury, secretary of the A.S.C.E., for national societies, and E. S. Nethercut, secretary of the Western Society of Engineers (Chicago), for local societies. Mr. Seabury described the work in the New York metropolitan area of the Professional Engineers' Committee on Unemployment. The discussion showed how action developing spontaneously among engineering groups throughout the country has resulted in the raising of private funds or the coöperation of public relief officials has results in providing cash or relief work to unemployed engineers.

Col. F. M. Gunby, president, emergency planning and research bureau, Engineering Societies of New England (Boston), told how his bureau collected a private fund of $100,000 to employ engineers in compiling city records, planning activities, and other useful projects. C. E. Sabin, told how in Cleveland engineers operated a farm for subsistence. Cleveland is reported to have the only full time employment service operated by a local society; it is expected that the service will be self-supporting this year.

Other subjects discussed at the secretaries' conference were problems in connection with dues of unemployed members, handling of bills, arrangements for successful meetings of technical societies, and new types of service and activities for local organizations.

Discussion as to interrelation of national and local activities resulting in the appointment of a continuing committee was led by C. E. Davies, secretary of the A.S.M.E., for the national societies, and J. S. Dodds, secretary of the Iowa Engineering Society, for the local societies.

Election of Officers

At the election of officers, no change was made in the present executive committee of Council. J. F. Coleman continues as president, having been elected for the 2 year term, 1935–36. Two of the 4 vice presidents, Paul Doty (A'04, M'12) and A. J. Hammond also are hold-over officers, serv-

ing for the 1934–35 term. The other 2 vice presidents, C. O. Bickelhaupt (M'22, F'28) and W. H. Woodbury were reëlected for the 2 year term beginning January 1935. C. E. Stephens (M'22) was reëlected treasurer to serve during the year 1935, as was William McClellan (A'04, M'09, F'12, and past-president) to serve as chairman of the finance committee for 1935. F. M. Feiker was reappointed executive secretary for 1935.

Representatives of the A.I.E.E. on the assembly of American Engineering Council, in addition to Messrs. Bickelhaupt, McClellan and Stephens, are F. J. Chesterman (A'20, F'22), J. Allen Johnson (A'07, F'27, and president) and H. H. Henline (A'19, M'26, and national secretary) alternate.

Another A.E.C. meeting is tentatively set for October when it is planned to bring together the boards of control of all the national societies toward the furtherance of unity of action.

Letters to the Editor

Mapping of Fields

To the Editor:

In Doctor Weber's paper on "Mapping of Fields" (see ELECTRICAL ENGINEERING for December 1934, page 1563–70) an excellent outline of the mathematical treatment of field problems is given, but graphical methods are only mentioned. In practical engineering work most field problems can be solved with sufficient accuracy by the graphical method sometimes referred to as the "method of curvilinear squares" or "curvilinear rectangles."

There are many worth while contributions by American authors to the development of the theory and application of this practical graphical method, in addition to those cited by Doctor Weber (references 15 and 22). The following list of additional references is not complete but should be of value to any one interested in acquiring a working knowledge of a practical method of solving field problems:

1. THE RELUCTANCE OF SOME IRREGULAR MAGNETIC FIELDS, John F. H. Douglas. A.I.E.E. PROC., v. 34, 1915, p. 1067–1125.

2. MAPPING MAGNETIC AND ELECTROSTATIC FIELDS, A. D. Moore. *Elec. Jl.*, v. 23, 1926, p. 355–62.

3. FUNDAMENTAL THEORY OF FLUX PLOTTING, A. R. Stevens, Jr. *G. E. Rev.*, v. 29, Nov. 1926, p. 794–804.

4. SYNCHRONOUS MACHINES, R. E. Doherty and C. A. Nickle. First of series of articles appearing in the A.I.E.E. TRANS., v. 45, 1926, p. 912–42.

5. ADDITIONAL LOSSES OF SYNCHRONOUS MACHINES, C. M. Laffoon and J. F. Calvert. A.I.E.E. TRANS., v. 46, 1927, p. 84–96.

6. GRAPHICAL DETERMINATIONS OF MAGNETIC FIELDS, A. R. Stevenson, Jr. and R. H. Park. A.I.E.E. TRANS., v. 46, 1927, p. 112–35.

7. GRAPHICAL DETERMINATION OF MAGNETIC FIELDS, E. E. Johnston and C. H. Green. A.I.E.E. TRANS., v. 46, 1927, p. 136–40.

8. A PRACTICAL APPLICATION OF GRAPHICAL FLUX MAPPING, J. F. Calvert. *Elec. Jl.*, v. 24, Nov. 1927, p. 543–7.

9. GRAPHICAL FLUX MAPPING—I, II, III, IV, V, VI, J. F. Calvert and A. M. Harrison. *Elec. Jl.*, v. 25, 1928; March, p. 147–50; Apr., p. 179–82, May, p. 246–8, July, p. 362–5, Aug., p. 399–401, and Oct., p. 510–13.

10. ANALYTICAL DETERMINATION OF MAGNETIC FIELDS—SIMPLE CASES OF CONDUCTORS IN SLOTS, B. L. Robertson and I. A. Terry. A.I.E.E. TRANS., v. 48, Oct. 1929, p. 1242–59.

11. FORCES IN TURBINE GENERATOR END WINDINGS, J. F. Calvert. A.I.E.E. TRANS., v. 50, March, 1931, p. 178–94.

12. SURGE PROOF TRANSFORMERS, H. V. Putnam. A.I.E.E. TRANS., v. 51, Sept., 1932, p. 579–84.

Reference 1 above is important due to the variety of experimentally determined examples and the immense bibliography or experimental work which is presented. References 2, 3, and 4 give in clear style the principles for simple fields. References 5, 6, and 9 give the basic principles for mapping electromagnetic fields either inside or outside the current source. Reference 9 gives the widest range of solutions with practical, though difficult, boundary conditions. Reference 7 compares experimental results with graphical determinations. Reference 10 shows mathematical solutions which check the data obtained graphically by the authors of some of the previously mentioned papers. References 8 and 11 show important applications to loss force and reactance problems. Reference 12 shows the introduction of the graphical method to complicated 2 and 3 dimensioned electrostatic problems which involve 2 or more dielectrics.

Very truly yours,

L. A. KILGORE (A'29)
(Power Engg. Dept., Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.)

To the Editor:

In his paper on "Mapping of Fields" (see ELECTRICAL ENGINEERING for December 1934, page 1563–70) Doctor Weber has set forth the position of field problems in contradistinction to circuit problems. I intend to discuss this point of view and hope to add certain other features which will be of interest.

In electrical engineering most problems may be divided as to time into steady state and transient, and as to space into circuit and field problems. The circuit problems are those in which the phenomena vary with time and with distance along paths of one dimension. Field problems deal with steady state or transient conditions in 2 or 3 dimensions. In the past, electrical engineers have found it most convenient to approximate the field problems by circuit analogies. The so-called magnetic circuit is perhaps the best known example. Such analogies no longer need be resorted to for the older types of problems and such analogies will not yield satisfactory solutions for the newer problems. In fact, there are many field problems encountered today in electrical engineering which require new methods based directly upon the fundamental concepts of physics, but in which simple methods of application have been devised.

It is in this latter particular that Doctor Weber has attached hardly sufficient importance to the graphical method of mapping by use of curvilinear squares for 2-dimensional problems, and by the use of suitable curvilinear rectangulars for 3-dimensional problems and for 2-dielectric problems. I should state here that some of the first efforts to develop and to illustrate numerous elements of this work, in its early stages of development for engineering use, were made by Prof. A. D. Moore at the University of Michigan. These methods, in which due consideration has been given to the graphical interpretation of the equations of La Place and Poisson, have been taught in the Westinghouse educational work since 1925. It has been found that a man possessing average ability for free-hand drawing can become sufficiently proficient after 3 to 4 weeks of intensive practice to use this method of solution for any field problems that he may encounter. This is a far less investment of time and energy than would be necessary to perfect the mathematical technique which would be required to solve even very simple problems. Incidentally, the mathematical methods are applicable only to problems with extremely simple boundary conditions as no others have been solved to date. The man with the training in graphical mapping does not encounter these limitations of hopelessly difficult boundary conditions. He should be able to solve 2-dimensional problems with any boundary condition whatever and any 3-dimensional problems which are cylindrically symmetrical, regardless of their boundary conditions. Also he should be able to solve electrostatic field problems containing materials of different dielectric constants.

This graphical method of solution for field problems is much more rapid than any other. A man with moderate skill should be able to solve almost any 2-dimensional field problem (with the exception, for instance, in the case of electrostatic fields of those containing 2 dielectrics) to an accuracy of about ±5 per cent for the flux density after working for about 1/2 hour. He should be able to obtain an accuracy of 1 to 2 per cent for the flux density within one day. If changing boundary conditions is to be considered (as, for instance, the opening of a contactor), about 4 maps usually will suffice to give satisfactory curve data.

In order that a man obtain such proficiency, it is necessary that he study a carefully selected set of possible boundary conditions. This may be accomplished as follows:

1. By developing the principles regarding: (*a*) Inside and outside corners, (*b*) slots, (*c*) the conditions around and within large and small conductors, (*d*) the method for replacing saturation effects or perhaps special parts of the field by current sheaths and perfectly magnetic material, (*e*) the use of images, and (*f*) the numerous methods for introducing and removing boundary conditions to get the greatest benefit from the superposition theorem.
2. To show a variety of boundary conditions which have been solved and to point out the principles used.
3. And most important, to develop skill of hand and eye and proper confidence by mapping fields in which one solves some practical problem.

I may say then that the graphical method is the most powerful with the possible exception of the experimental method, and it is certainly the best adapted for engineering use of any of the known methods for solving steady state field problems. The mathematical details can be omitted almost entirely. In fact, the rapid advances in this phase of the art only occurred after these mathematical details were omitted. In this particular, the steady state field problems seem to be at the opposite end of the scale from the transient circuit problems, for in attacking transient circuit problems, complex mathematical solutions seem to yield the best and quickest results, and in many cases to furnish the only method of obtaining analytical solutions.

Very truly yours,

J. F. Calvert (A'27)
(Power Engg. Dept., Westinghouse Elec. and Mfg. Co., E. Pittsburgh, Pa.)

Engineers in Elective Public Office

[Note: The writer of this letter was elected Mayor of his home town, in New Jersey, in 1928. In 1929 and 1930, before the depression had turned men's minds toward economy in government, Mr. McNicol reduced taxes locally 36 points in his first year. Following years showed further reductions notwithstanding that a modern incinerator was erected, a half-million dollar school built, a major sewer project carried out, and miles of new concrete sewer laid. To date this town has continued all municipal and school salaries minus only the 10 per cent required by State action in the general relief program. At the end of his first term Mr. McNicol was reëlected for 2 more years without opposition from either Democrats or Republicans.]

To the Editor:

For several years before Mr. Hoover took office as President of the United States there had been occasional discussion in engineering circles and in engineering periodicals on the general subject of the engineer in politics. Because in those days engineers were busy men, and making money, too often the talk was of a facetious character. Engineers, in common with most professional men, looked upon "politics" as a somewhat sordid occupation having precarious returns. A result was that there were few engineers who sought public office by the elective route.

The attainment of the high office of President by Herbert Hoover, the engineer, brought to the engineer-in-politics discussions a serious, general entertainment of the idea of public service as individual contributions toward local and national welfare. It was intriguing to read and study the many contributed articles from engineers which appeared in the engineering journals from 1928 until recently, advancing the writers' ideas as to what the engineers' contribution to or participation in government might well be in the interests of the general welfare.

When the debacle of 1929 descended upon the nation, a general mess was precipitated which no individual nor any group will ever admit responsibility for—quite rightly. The political overturn in national administration which followed seemed natural in view of what had been going on for 20 years: "natural" when we stop to analyze what actually had been going on.

Perhaps it was because there had been much discussion of the engineer in politics for some years prior to 1933 that widespread attention was accorded the forced-draught proposals of the "technocrats" early in the days of the present administration. That the technocrats (whoever they were) were accorded a patient hearing, and were granted so much space in the public press, was mainly a sign of the times. 125,000,000 men and women, since the war years had had sold to them annually the glories of an American standard of living to which each and all were said to be by right entitled. In 1932 it was all too plain that the politician-salesmen had failed dismally to make good their campaign promises. The citizenry was stunned. The people were groping. There was somewhat vengeful seeking for scapegoats. And, although scapegoats had been named and had been expelled from Washington, it was late in 1933 before the people at large reluctantly conceded what engineers had known all along, that technocracy contained no panacea—in fact was as grotesque in its fulminations as various others of the shibboleths of 1932 were in 1933 suspected to be, and in 1934 are believed to be.

Engineers who today read the many contributions on economics, social reconstruction and government which appear monthly in their respective trade journals, are aware that they as American citizens are aided most in their thinking by writers who have little faith in nostrums, but who have recalled for consideration as factors human nature, emotional attributes, the old rather than socialistic notions of liberty, and older and saner ideas related to impracticable horizontal standards of living.

Aside from what engineers are thinking about the commonwealth, what they are thinking about their own situation during the present instability, may be epitomized by a quotation from the August message of J. Allen Johnson, president of the A.I.E.E. (Electrical Engineering, August 1934, page 1142). He says: ". . . . . In several of these movements one or the other of 2 objectives seems to predominate. One of these is the *professional* advancement, the other the *economic* advancement of engineers." The context is not difficult to imagine. It is the same as would precede similar statements made by the leaders of numerous trades and professions at the present time.

It is axiomatic in engineering that the bolt must hold if the bridge is to hold. During the long period of industrial expansion and progress in this country it was axiomatic also that a foreman in charge of a small job had the best opportunity to learn the truth about the requirements of larger jobs. An engineer finding himself in an elective public office very early senses that he is engaged in an undertaking that bears some relation to other public offices, as to size and responsibility. He realizes also that no matter what the magnitude of the office he shall continuously be in contact with the same people who would have placed him in any one of the other administrative positions, whether farther up or farther down the scale of magnitude of public office. I say elective office, because if an engineer attains public office he must travel the same route thereto as the practical politician, the ward-heeler who has waited long on the party's waiting list, and the candidates of the lobbies and blocs.

The fact that this is so has deterred very many engineers from seeking public office. This is a fault of their academic education. Could educational authorities realize their opportunities and responsibilities in this respect the halls of learning might make constructive contributions toward good government. It is true that at the moment there is rather a glut of professors in key posts at the seat of national government. These men are in my opinion starting at the top of the ladder. They have missed much that should now be of value to them and to the country had they started at the bottom. My notion is that men (and women) should be educated and trained for public office beginning in the smaller offices in their own communities, such as councilmen, assessors, treasurers, municipal clerks, mayors, State assemblymen, and so on.

In almost any municipality in America tonight a hundred, or a thousand educated men are playing bridge, or listening to the radio, while down town at the council meeting one of the town fathers is heard to say: "Youse guys make me sick." And, no doubt, the gentleman has supportable reason for the remark.

The most difficult task an engineer, or anyone else, has in public office is that of being a reasonably good fellow and at the same time give the taxpayer a square deal. Some few men have the faculty. More could measure up in this respect if organized education provided for it. As an indication it may be said that the mayor of a town of, say, 10,000 population, will during his term sign checks paying out 1,000,000 dollars collected from 4,000 taxpayers. An early enlightening discovery is that about one half of the tax money collected is paid out for what the school folks call "free education." With a hospitality of mind and with the knowledge that he is the custodian of all tax money, a mayor, depending upon the type of his business training, may decide to gather data and statistics bearing on school costs. To accumulate even a fairly accurate file on the subject, he is successful in proportion to his persistence, skill in analysis, adroitness, suavity, and any other attributes he may be able to exercise. The fact that this is the case does not mean the educational authorities have anything special to conceal. Their reasons for resenting inquiry are the same as those which should be advanced by all the various other organized groups in America should inquiry be suggested.

Of course a mayor, the custodian of the money gathered in by the tax collector, can without doubt find no end of ways of spending his time, other than bothering about what is done with the money after he signs the appropriation checks, but this is the type of mayor that education should deliver us from if the vast sums appropriated for education are to be expended properly.

In the metropolitan dailies and in magazine articles in recent months there have been charges emanating perhaps from uninformed as well as informed sources to the effect that American educational institutions have become hotbeds of socialism and even of communisn. I know many school teachers and I feel sure that each of them would indignantly deny that they themselves are socialists, or socialistic in thought. However, if it is true that altogether too many of present-day school graduates are communistic in thought and in attitude toward life would it be unreasonable to suspect that in reality they have for years passed through an atmosphere that is socialistic without its being recognized as such, either by student or by teacher? Consider the teacher's state of mind with respect to his own and her own status in life; security economically. A woman from the national educational office, Washington, in a recent one of many radio addresses informed the listeners that there are "A million school teachers interested in this . . . . ." What it was they are interested in I did not catch, but the official in Washington, on the taxpayers' payroll said it in a tone that plainly meant "a million votes."

Through this voting power in State assemblies in the past quarter century the school folks have provided themselves with pensions and tenure of office, mandatory legislation, and 14 weeks vacation annually, with full pay, in addition to all the single holidays. All of this is lifted out of the hands of the local taxpayer who pays the bill. These "mandatory" laws are maintained on the statute books by labels pinned on State assemblymen and senators: "Fair to Education," which automatically assures these gentlemen from 25,000 to 50,000 votes over-all, depending upon the State.

In a recent radio address William Allen White reminded his hearers that the one big inducement that both communism and socialism offer is "economic security." Mr. White reminded also that the complement of perfect economic security must be tyranny.

In listening by radio to the propaganda that goes out from the United States office of education at Washington, castigating any citizen or taxpayer who "says a word against education," it is quite plain to this writer why about one-half of the municipal tax collection is expended for education. "In Union there is Strength."

Parents who dream or wish that their sons may become Thomas A. Edisons or James J. Hills, may be puzzled over socialistic ideas brought home from school, but should not blame individual school teachers for this. The teacher may be entirely innocent of exercising such an influence. An outlook on life supported by economic security, on the other hand, may not be just the right influence for boys and girls who are going out into a world where if they are to enjoy liberty and freedom, attain high professional standing, and be in a position to acquire a competence enabling them to maintain liberty and freedom in their later, unproductive days, they must be free from the tyranny which follows leveling economic security dependent upon tax money which itself might likely collapse under the strain.

The remaining one-half of the municipal tax collection is disbursed in the support of a dozen or more public services, each one subject to much the same analysis as is the bill for schools. Now that bureaucracy in the national government is establishing new high records in the number of voters supported on the public payroll there is little point in devoting time to complaining about this situation in the cities and towns. On this score, however, it may be noted here that we shall have socialistic government in the United States, or in its component parts, when those on the public payrolls outnumber the self-supporting taxpayers and voters *who bother to go to the polls on election day.*

Many business and professional men and women wonder why the educational folks do not sense that in justification of the enormous increase in the cost of education, per pupil, during the past 30 years, they should desire to show improvement in output. Demands for "larger" and "better" school buildings very rarely originate among taxpayers, or the parents of school children. The demands are initiated, fostered, and nurtured within the system itself. Consider California. There in sparsely populated communities school edifices supportable from reasonable taxation have been supplanted by magnificent architectural structures located on 10 to 15 acre ground areas. The country is strewn with grade schools which in appearance and equipment rival the large universities.

The taxpayer proverbially remains ignorant of the situation until the day of reckoning comes—when he learns that the public debt is his debt. I have before me the investment folio of one of the mutual insurance companies. The company lists $5,012,875 invested in school district bonds, the investments in 48 districts throughout the United States. Seventeen of these investments are in Illinois and but one in California. In gauging the profit, the output, from the enormous school investment, an analyst not gifted with the prescience enabling him to look ahead 20 years, might perhaps be unfair should he attempt to evaluate what the daily press during the past year reported with respect to conditions, say, in California.

Aside from engineering training, engigineering instinct alone prompts one to look for and expect to find commensurate return from investment. In 30 years, while billions of dollars have been appropriated for "education" the educators uninterruptedly encouraged the taxpayers with the reminder that these vast sums were actual investments: that there should be return, with interest, the return being measurable in improved knowledge, self-sustaining capacity, and in citizenship equipped to *support* government.

A question is, is this or is it not the achievement. If the billions appropriated for education have not produced the desired results, should opprobrium attach to any one, even an engineer, who inquires for the reasons for failure?

At the meeting of the New York Section of the Institute on October 10, last, Dr. Virgil Jordan said (see ELECTRICAL ENGINEERING, November 1934, page 1546–51):

> ". . . Among the figures that move in this economic scene, only he (the engineer) can save this great mass of humanity from self-destruction. And he must not expect to be thanked for it. The mob that rules destiny today in all the western world will take his service for granted, it will not show any gratitude for it because they have no understanding of its essential significance at all."

Remember, this *mob* has been put through our schools in the last 2 or 3 decades.

That astute commentator H. L. Mencken, in a recent article in *Liberty*, says with respect to the genus politician:

> "How are we to improve him—or get rid of him? The first, I believe, is a sheer impossibility. So long as we want to enjoy the excitement of democracy we must be prepared to endure its curses, and one of them is the fact that when 2 men stand up before a mob, the one honest and the other a fraud, the mob always prefers the fraud."

In order to make himself understood Mr. Mencken exaggerates somewhat when he says "always." However, he speaks of the same school product that Dr. Jordan speaks of.

More and more it appears that the school system has become a sort of Empire in its own right, the laws passed for its perpetuation having been prepared largely by persons on the school payrolls. Often in late years we have heard the belief expressed that the educational system is ingrown. A solution of this vast problem in the interest of the oncoming generations of Americans might be accelerated should the educators settle upon and announce fundamental objectives; decide to devote say 90 per cent of school time and school funds to these objectives, and change the propaganda accordingly.

There is just no question about it but that engineers are particularly equipped for administrative public office, but unless by conference with the educators they can prevail upon these gentlemen to so apply the money appropriated for education that something other than mobs are turned out, we might as well sit back placidly and wait for the circuses supported from tax money to begin, and for the spears of the Numidians to herald the end.

Very truly yours,

DONALD MCNICOL (A'05, F'18)
(Editor, *Radio Engineering*, New York, N. Y.)

First Electric Street Railway

To the Editor:

I am enclosing an interesting clipping from one of our local papers on the above subject which establishes, quite definitely, the date of November 16, 1886 as the date when Scranton's first electric street car was put into service.

There is local pride in the thought that this was the "first electric street car" put into operation and there may be local pride in other localities where cars were placed in operation about the same time and possibly at earlier dates.

You, doubtless, have information on this subject and possibly it may have been pub-

lished and has not come to the writer's attention.

I will appreciate any advice you may be able to give on this subject.

Very truly yours,

W. A. Thomas (A'05, F'13)
(Consulting Engineer,
Scranton Electric Bldg.,
Scranton, Pa.)

Editor's Note: In response to the above inquiry, the following information is offered.

In Electrical Engineering for May 1934, page 698–701, the late Dr. F. J. Sprague (A'87, M'98, F'12, HM'32, member for life, and president 1892–93) gives some information of his own and some references to other information which may be of value in this connection.

On page 841 of this same issue, there appears under the date of 1888, among other entries, the following: "First electric street railway (Richmond, Va.)." This particular statement unfortunately should have read as follows: "First city-wide urban electrical street railway operated, Richmond, Va." According to the best information that we have been able to obtain, the Richmond installation is generally regarded as the first commercially successful electric street railway "system," although various authorities recognize definitely the fact that a few street cars were operating on short lengths of track in various cities in the United States prior to the completion of the Richmond system. It seems to be authenticated that the Richmond system was given preliminary try-outs in the fall of 1887 and placed in fully commercial operation as a completed system in May of 1888. This system is believed to have comprised some 11 miles of track and 40 cars, which number of cars Doctor Sprague characterized as being more than the total of street railway cars operating in all other cities in the United States at that time.

Further interesting information is given on page 186 of the A.I.E.E. Transactions, volume 4, 1887, where the late T. Commerford Martin (A'88, M'10, president 1887–88) under the title of "A Few Comparative Statistics of Electric Railways," reported the following:

1. Baltimore, Md., 1885, 2 miles of track (single track with turnouts) 6 "motors and motor cars"
2. Los Angeles, Calif., 1887, 3 miles of track, double and single, 8 "motors and motor cars"
3. Port Huron, Mich., 1885–86, 4 miles of single track, 8 "motors and motor cars"
4. Windsor, Canada, 1885, nearly 2 miles of single track, 2 "motors and motor cars"
5. Highland Park, Detroit, Mich., 1886, $3^1/_2$ miles of single track, 2 "motors and motor cars"
6. Dix Road, Detroit, Mich., 1886, $1^3/_4$ miles of single track, 4 "motors and motor cars"
7. Appleton, Wis., 1886, $4^1/_2$ miles of single and double track, 8 "motors and motor cars"
8. Scranton, Pa., 1886, $3^1/_4$ miles of single track with 4 sidings, 3 "motors and motor cars"
9. Denver, Colo., 1886, $3^1/_2$ miles of single and double track, 7 "motors and motor cars"
10. Montgomery, Ala., 1885–86, 11 miles of single and double track, 18 "motors and motor cars." (Special notation that "this line ran 2 cars one year. Has just started other cars.")

The above listing was given as of May 18, 1887, supplemented by brief information on many lines under construction, and concerning many new companies formed and forming for the purpose of building street railway systems in many different cities.

(For the purpose of establishing the correct dates in electrical history of 50 years ago, and giving credit where it is due, further contributions along this line will be welcomed by the editor.)

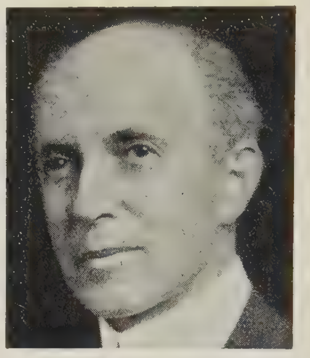
Personal Items

E. F. W. Alexanderson (A'04, F'20) consulting engineer, General Electric Company, Schenectady, N. Y., has been elected to membership in the Royal Academy of Science, Sweden. Doctor Alexanderson was born at Upsala, Sweden, and graduated from the Royal Institute of Technology at Stockholm in 1900. He later studied in Berlin, and in 1926 received the honorary degree of doctor of science from Union College, Schenectady, N. Y. In 1902 he entered the General Electric Company, but also was chief engineer of the Radio Corporation of America 1920–4. Doctor Alexanderson is well known for his contributions to radio, which include the Alexanderson high frequency alternator, multiple tuned antenna, vacuum tube radio telephone transmitter, and tuned radio frequency receiver. He has been concerned also with television, electric ship propulsion, and railroad electrification, and has presented a number of technical papers. Among the honors which he has received are decoration with the Order of the North Star, Sweden, and the Order of Polonia Restituta, Poland, the gold medal of the Institute of Radio Engineers, and the John Ericsson medal. Doctor Alexanderson is a fellow and past-president of the Institute of Radio Engineers, and a member of the American Physical Society, and Sigma Xi.

C. E. Stephens (M'22) vice president of the Westinghouse Electric and Manufacturing Company, New York, N. Y., was reëlected treasurer of American Engineering Council for the term of one year at the meeting held in Washington, D. C., January 10–12, 1935. Mr. Stephens, who is a representative of the Institute on the assembly of Council, has for a number of years been active on committees of the Institute, being at present chairman of the committees on code of principles of professional conduct, and the Edison Medal.

C. O. Bickelhaupt (M'22, F'28) assistant vice president, American Telephone and Telegraph Company, New York, N. Y., was reëlected a vice president of American Engineering Council for the 2-year term 1935–36, at its annual meeting held in Washington, D. C., January 10–12, 1935. Mr. Bickelhaupt, a representative of the Institute on the assembly of Council, is also chairman of the Institute's publication committee. A brief biographical sketch of Mr. Bickelhaupt's career was given in Electrical Engineering for October 1934, page 1428.

F. B. Jewett (A'03, M'10, F'12, and past-president), vice president of the American Telephone and Telegraph Company, and president of the Bell Telephone Laboratories, Inc., was unanimously awarded the Faraday Medal of the Institution of Electrical Engineers (of Great Britain) at a meeting of the council of that organization on January 24, 1935. A biographical sketch of Doctor Jewett's career appears in Electrical Engineering for January 1935, page 140.



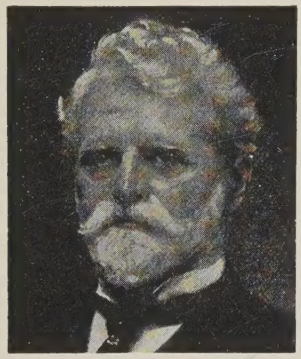
F. B. JEWETT

William McClellan (A'04, M'09, F'12, and past-president) president of William McClellan and Company, Ltd., and of the Potomac Electric Power Company of Washington, D. C., was reëlected chairman of the finance committee of American Engineering Council for 1935, at its meeting held in Washington, D. C., January 10–12, 1935. For a period of over 20 years, Doctor McClellan has continuously served the Institute as a member of its technical committees, being at present a member of the committee on Institute policy, and a representative on the assembly of American Engieering Council. A biographical sketch of Doctor McClellan's career was given in Electrical Engineering for May 1934, page 804.

A. F. Hamdi (A'18, M'21) has become chief of the bureau of electrification in the ministry of economy of the Republic of Turkey, with headquarters at Ankara, the Turkish capital. According to Mr. Hamdi "the bureau of electrification, as its name implies, has been created to develop the energy resources of the republic—coal, water, oil—in order to supply cheap power to the budding industries." A native of Turkey (Constantinople 1891) Mr. Hamdi migrated to the United States in 1911, graduated from Columbia University, New

York, N. Y., in 1916 with the degree of electrical engineer, receiving the next year the degree of master of arts in physics. After graduation in June 1916, Mr. Hamdi served Columbia University as an assistant in the electrical engineering laboratory; for several subsequent years he taught evening school classes at Columbia University and Cooper Union in New York City. Mr. Hamdi was first employed by the New York Edison Company in 1917 as a laboratory assistant in its test department; in 1918 he was made foreman of the standardizing laboratory, and in 1919 was made a general foreman in the test department, a position he held until 1924 when he was promoted to the position of assistant engineer of the test department; from 1927 to 1929 he was assistant engineer in the meter department where he was particularly interested in research and development work in connection with measuring devices and methods, and testing equipment. From 1929 to 1932, Mr. Hamdi served the Hall Electric Heating Company, Inc., of Philadelphia, Pa., as engineer. Subsequently he returned to Turkey.

Ambrose Swasey (HM'28) chairman of the board, The Warner and Swasey Company, has had the Washington Award for 1935 bestowed upon him. Exercises for the formal presentation of this award of the Western Society of Engineers (Chicago) will be held in Chicago, February 20, 1935. Doctor Swasey, famous manufacturer of precision instruments and mechanisms, has long been devoted to furthering the advancement of the engineering profession. It was he who in 1924 founded The Engineering Foundation, research agency of the 4 national societies of civil, mining and metallurgical, mechanical, and electrical engineers. Since its founding, Doctor Swasey has contributed gifts totaling $750,000 to the Foundation. A biographical sketch of Doctor Swasey's career was given in Electrical Engineering for May 1934, page 815.



AMBROSE SWASEY

F. M. Farmer (A'02, F'13) vice president, chief engineer and director, Electrical Testing Laboratories, New York, N. Y., has been reëlected vice chairman of the standards council of the American Standards Association. Mr. Farmer is chairman of the Institute's committee on research and a member of the committees on power transmission and distribution and coördination of Institute activities. A biographical sketch of Mr. Farmer was given in the February 1934 issue, page 231.

R. M. Spurck (A'18) General Electric Company, Philadelphia, Pa., formerly assistant manager of the switchgear engineering department, has been named manager of sales of the circuit breaker section of the switchgear sales division. Mr. Spurck is a graduate of the University of Illinois, and has been with the General Electric Company since 1910. He was a member of the Institute's protective devices committee 1928–30.

J. T. Holmes (M'24) who for 20 years has been chief engineer of The Frink Corporation, Long Island City, N. Y., resigned on January 9, 1935. Mr. Holmes has not as yet announced his future activity, but will probably continue in the line with which he has been associated. He has been a member of the Institute's committee on the production and application of light since 1933.

R. P. Brown (A'10, M'13) president, The Brown Instrument Company, Philadelphia, Pa., has become an officer and director of the Minneapolis-Honeywell Regulator Company with the consolidation of the 2 companies. He will continue as president of The Brown Instrument Company, which will maintain its present offices.

O. B. Blackwell (A'08, F'17) director of transmission development, Bell Telephone Laboratories, Inc., is now a member of the standards council of the American Standards Association, representing the telephone group. At one time Mr. Blackwell served on the Institute's communication committee.

K. T. Compton (F'31) president, Massachusetts Institute of Technology, Cambridge, Mass., has been appointed chairman of the board of technology of The American Society of Mechanical Engineers. Doctor Compton recently was elected president of the American Association for the Advancement of Science.

J. H. Milbyer (A'19) formerly superintendent of the Niagara, Lockport and Ontario Power Company, Olean, N. Y., has recently become district superintendent of the Tonawanda Power Company, North Tonawanda, N. Y.

E. A. Strong (A'30) formerly operator in charge of station CJRW, James Richardson and Sons, Ltd., Fleming, Sask., Can., is now engineer in charge of station CKCK, Leader-Post Publishing Company, Ltd., Regina, Sask.

S. E. Warner (A'31) resigned in June 1934 as instructor in electrical engineering at Rensselaer Polytechnic Institute, Troy, N. Y., to become chief engineer of W1XBS, a pioneer high fidelity radio station at Waterbury, Conn.

J. T. Lusignan, Jr. (A'27) former chief electrical engineer, Ohio Insulator Company, Barberton, Ohio, is now engineering assistant to vice president, of the parent company, the Ohio Brass Company, Mansfield.

W. C. Jessup (A'03) formerly district manager, Cutter Electrical and Manufacturing Company, New York, N. Y., recently became district manager for the I-T-E Circuit Breaker Company with offices in New York.

Alex Dow (A'93, F'13) president, Detroit Edison Company, Detroit, Mich., resigned recently as chairman of The American Society of Mechanical Engineers' committee on the thermal properties of steam.

R. W. MacGregor (A'30) formerly in the commercial department, Winters National Bank and Trust Company, Dayton, Ohio, is now operating a stock farm at Cedarville.

C. B. Seibert (A'32) has recently become an instructor in electrical engineering at West Virginia University, Morgantown. He had previously spent 3 years with the General Electric Company in Lynn, Mass.

A. L. Ross (A'33) formerly junior electrical engineer, Noranda Mines, Ltd., Noranda, Que., Can., is now in the engineering and production department of the Canadian Controllers Limited, Toronto, Ont.

C. F. Walter (A'27) former designing engineer, James R. Kearney Corp., St. Louis, Mo., is now paint supervisor for the Chevrolet Motor Company, Kansas City, Mo.

E. R. Swanson (A'26) formerly district engineer, Wisconsin Power and Light Company, Fond du Lac, has been transferred to Mineral Point, Wis., where he is district manager for the company.

A. F. Briggs (A'33) recently office engineer, U. S. Coast and Geodetic Survey, Port Arthur, Texas, has entered the electrical engineering department of the Sun Oil Company at Beaumont.

L. M. Keating (A'22) who has been with the McGraw-Hill Publishing Company, Inc., in Cleveland, Ohio, is now in the Detroit, Mich., office of the United States Advertising Corporation.

E. C. Curtis (A'31) formerly switchgear specialist with the General Electric Company, Portland, Ore., is now an electrical engineer with Ford, Bacon and Davis, Seattle, Wash.

H. G. Barnett (A'33) Corvallis, Ore., is assisting in an investigation of electric fish screens for the U. S. Bureau of Fisheries, with reference to the Bonneville dam project.

C. H. LYDALL (A'20) who recently went to London, England, with the firm of Merz and McLellan, has returned to the United States and is now with Sargent and Lundy, Inc., Chicago, Ill.

I. D. BLOCK (A'34) formerly with the Buffalo, Niagara, and Eastern Power Corporation, Buffalo, N. Y., is now with the 29th pursuit squadron at Albrook Field, Canal Zone.

CROSBY FIELD (A'14, F'22) vice president, Brillo Manufacturing Company, Brooklyn, N. Y., has been appointed a member of the committee on unemployment of The American Society of Mechanical Engineers.

W. J. REY (A'23) who lately has been in Ober-Arth, Switzerland, is now assistant electrical engineer, national park service, Department of Interior, Washington, D. C.

F. P. LAWRENCE (A'25) general plant manager, New York Telephone Company, has been transferred from New York, N. Y., to Albany, N. Y.

J. B. HARRIS, JR. (A'17) formerly president of Harris and Butler, Philadelphia, Pa., is now connected with the Rumsey Electric Company in that city.

THEODORE VARNEY (A'05) until recently a consulting engineer with offices in New York, N. Y., has accepted a position with Aluminum Limited, Montreal, Que., Can.

A. H. HARVEY (A'29) sales engineer, Inniss and Riddle (China) Ltd., has been transferred from Hongkong to Shanghai, China.

L. H. C. BEERSTECHER (A'19) manager, International General Electric Company, Inc., formerly at Soerebaia, Java, Dutch East Indies, is now at Batavia, Java.

A. H. BROWN, JR. (A'33) until recently in Cleveland, Ohio, is now with the American Transit Association, New York, N. Y.

W. T. LAWRENCE (A'32) of Chicago, Ill., has accepted a position as sales engineer with the Automatic Electric Company in New York, N. Y.

SIR ARCHIBALD PAGE (F'29) formerly general manager of the British Central Electricity Board, London, England, has been appointed chairman of the board.

G. E. ROLSTON (A'30) General Cable Corporation, has been transferred from Rome, N. Y., to New York, N. Y.

R. B. MACLAUGHLIN (A'32) Acme Meter Service Corporation, has been transferred from Philadelphia, Pa., to Boston, Mass.

G. F. RUCKER (A'32) is now a service engineer with Leeds and Northrup Company, Los Angeles, Calif.

P. F. MUNKASY (A'33) of Bridgeport, Conn., is now working with the U. S. Coast and Geodetic Survey, Panama City, Fla.

J. E. PEEK (A'32) acoustical engineer, Oklahoma City, Okla., has formed the Film Speaker Company in that city.

M. B. STEELE (A'28) sales engineer, Steel and Tubes, Inc., has been transferred from Cleveland, Ohio, to Boston, Mass.

Obituary

GEORGE ANSON HAMILTON (A'84, M'84, F'13, HM'33, and member for life) Elizabeth, N. J., died January 10, 1935. He was one of the 6 living charter members of the Institute, and the last surviving member of the original committee of 5 on organization. Mr. Hamilton was born at Cleveland, Ohio, December 30, 1843. He became interested in electricity, and built a small telegraph line for himself at Limaville, Ohio. In 1861 he became a messenger at Salem, Ohio, but 2 months later was made manager of the Ravenna office of the Atlantic and Great Western Railroad. Illness forced him to relinquish this position in 1863, but upon his recovery he went to Pittsburgh, Pa., as operator and manager of the Inland Company. Two years later he became manager of the office at Franklin, Pa., of the United States Telegraph Company, returning to Pittsburgh in 1866 as chief operator and circuit manager and remaining there until 1873 when the company was absorbed by the Western Union Telegraph Company. During 1873–75 he was assistant to Prof. Moses G. Farmer of Boston, Mass., who was engaged in the manufacture of general electrical apparatus and machinery and who later became an Honorary Member of the Institute. This work afforded him an opportunity to secure valuable practical knowledge of mechanics and to participate in many electrical experiments in telegraphy and other developments. In 1875 Mr. Hamilton was called to New York, N. Y., as assistant electrician to the Western Union Company. During the next 2 years, with Gerritt Smith, he participated in the establishment of the first quadruplex telegraph circuits to be put into operation, and with Mr. Smith was also the first to introduce the system in England. Upon his return to this country he carried out experiments preliminary to establishing the wheatstone high-speed automatic system in this country. In 1889 Mr. Hamilton accepted a position with the Western Electric Company, New York, N. Y., supervising the department for the production of fine electrical instruments. He retired in 1909. In addition to having been a charter member of the Institute and active in its organization plans, he served as the Institute's first vice president for the term 1884–86, and was a member of the first committees on editing and permanent quarters. From 1895 to 1930 he served the Institute as national treasurer, and in 1933 was elected an Honorary Member. He was a member of the Edison medal committee 1908–30, and of the executive committee 1914–30. Mr. Hamilton was a member of the Institution of Electrical Engineers (Great Britain), Société Française des Électriciens, Société Française de Physique, and Société Belge d'Astronomie.

THOMAS AUGUSTUS WATSON (F'15) retired, Boston, Mass., died at his winter home in St. Petersburg, Fla., on December 14, 1934. He is famous as the first person to receive a message over the telephone. Doctor Watson was born at Salem, Mass., January 18, 1854, and attended schools there and at Massachusetts Institute of Technology. In 1875 Alexander Graham Bell (A'84, M'84) inventor of the telephone, who died in 1922, employed Doctor Watson to work with him. The first successful apparatus was made by Doctor Watson, and it was over this that the inventor spoke the first telephone message, "Watson, come here; I want you." As superintendent of the first Bell Telephone Company he did much of the engineering work during the period 1877–81, designing calling and switching apparatus and other mechanical and electrical devices. Doctor Watson was principally responsible for the substitution of the all-iron diaphragm for the membrane with a piece of iron at its center, and he also experimented to find the best size and thickness for the diaphragm and the effect of a closed chamber behind it. The universally-used polarized-armature telephone bell is credited to Doctor Watson, as is also the repeating coil used in producing a phantom circuit between metallic conductors and ground. After leaving telephone development work in 1884 he became a member of the shipbuilding firm of F. O. Wellington and Company, and from 1900 to 1903, when he retired, he was president of the Fore River Ship and Engine Company. He received the honorary degrees of master of arts, Union College, 1919; doctor of engineering, Stevens Institute of Technology, 1921; and doctor of sciences, University of New Hampshire, 1929. Doctor Watson was also a member of the American Association for the Advancement of Science.

W. ROY MCCANNE (A'19) president and general manager, Stromberg-Carlson Telephone Manufacturing Company, Rochester, N. Y., died November 5, 1934. He was born at Jacksonville, Mo., December 29, 1878. In 1897 he entered the office of Charles H. Ledlie, a civil and electrical engineer of St. Louis, Mo., and while there assisted in the construction and operation of the Kinloch Telephone Company's exchanges in St. Louis and its toll lines in Illinois and Missouri, together with similar work for other telephone and power companies. In 1905 the group controlling the Kinloch properties became interested in the Stromberg-Carlson Company, and Mr. McCanne was sent to Rochester. The following year he was elected treasurer and director of the company. For a short time, 1911–12, he was with the Eastman Kodak Company, Rochester, but returned to the former company as general manager. He was elected

president in 1924, in which year, with his direction, the company expanded to produce radio receivers. Recently he was one of those to confer with officials in charge of the government's industrial control program relative to the radio industry.

Alfred W. Kiddle (A'05) patent attorney and senior member of the law firm of Kiddle, Bethell, Montgomery, and Halbert, New York, N. Y., died January 7, 1935. He was born at New York August 9, 1865, and studied at the College of the City of New York and Columbia University, receiving the degree of bachelor of laws from the latter. In 1887 he was admitted to the bar, after having been employed in the patent department of the Edison Electric Light Company since 1883. After admission to the bar he made a specialty of patent law, preparing numerous applications for patents on electrical inventions and including also litigations involving electrical patents. He had served as special counsel to the City of New York on patent cases. During the period 1919–26 he was a member of the library board of the United Engineering Societies, now the United Engineering Trustees, Inc. Mr. Kiddle was a fellow of the American Society of Civil Engineers, and a member of the American Bar Association, American Patent Law Association, New York Patent Law Association, Association of the Bar of the City of New York, and other organizations.

Philander Norton (A'11) assistant to the president, Bell Telephone Laboratories, Inc., and editor, *The Bell System Technical Journal*, New York, N. Y., died on January 10, 1935. He was born at Elmira, N. Y., March 2, 1882, and was a graduate of Princeton University, receiving the degrees of bachelor of arts in 1907, master of arts in 1908, and electrical engineer in 1910. In the latter year he was employed in development work by the laboratories of the Western Electric Company in New York, this organization later becoming the Bell Telephone Laboratories. Among the devices on which he worked were ringing systems for party lines and protective apparatus, and to him is credited the automatic ringing system commonly used. At the time of the World War he was engaged in the production of vacuum tubes and also on methods for submarine detection. In 1920 he was placed in charge of the testing of new telephone apparatus, and 5 years later, with the organization of the Bell Laboratories, was appointed assistant to the president. Since 1929 he had been editor of the journal.

William Corbit Spruance, Jr. (A'06, M'07) vice president and director, E. I. du Pont de Nemours and Company, Wilmington, Del., died January 9, 1935. He was born at Wilmington, September 26, 1873. In 1890 he graduated from the Friends School at Wilmington and entered Princeton University, where he studied civil and electrical engineering, receiving the degree of electrical engineer in 1895. After a short time in the apprentice course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., he was employed in the office of Montgomery Waddell (A'88, M'88, and member for life) a consulting engineer, where he worked on the design and construction of meters, etc. Following this he was employed by the Wilmington City Electric Company, and in 1899 opened office as a consulting engineer, being concerned with electrical work for the du Pont Explosive Company and subsidiaries. During the World War he served in the ordnance reserve corps and was commissioned a colonel. In addition to his Institute membership Colonel Spruance was a member of The American Society of Mechanical Engineers, the American Institute of Mining and Metallurgical Engineers, the American Academy of Political and Social Sciences, and the Franklin Institute.

Dana Pierce (A'11, F'28) president, Underwriters Laboratories, Inc., Chicago, Ill., died on December 18, 1934, in Atlantic City, N. J. He was born at Claremont, N. H., April 11, 1871, and received the degree of bachelor of arts from Amherst College in 1892, subsequently taking special work at Cornell and Johns Hopkins universities. From 1900 to 1906 he was an instructor in physics at Pratt Institute, Brooklyn, N. Y., and from then until 1916 was an engineer in the Underwriters Laboratories. In 1916 he became vice president of the laboratories, and president in 1923. Mr. Pierce was chairman of the electrical committee of the National Fire Protection Association for 10 years, and for 2 years, 1926–28, was president of that association. He was active in work on standards and codes for testing and for safety in electrical engineering.

William McLellan (A'03, F'13) consulting engineer, Merz and McLellan, Newcastle-upon-Tyne, England, died on December 12, 1934. He was born at Kircudbrightshire, Scotland, in 1875, and studied at what is now Liverpool University, Liverpool, England. The partnership was formed in 1899 and carried out a number of power and railway electrification projects, including work in South America, India, and Australia, as well as in England.

Donald P. McNitt (A'27) consulting engineer, St. Louis, Mo., died during 1934, according to word recently received at Institute headquarters. He was born at Red Cloud, Neb., November 25, 1894, and was a graduate of the electrical engineering course at Washington University, St. Louis. For a time he was employed by the LaPorte Water, Light, and Ice Company, LaPorte, Tex., and later by the Continental Motors Company and the Kelsey Wheel Company, both in Detroit, Mich. During 1918–20 he was an electrician in the U.S. Navy. From 1921–27 he was employed by the Weckermeyer Electric Company, East St. Louis, and subsequently became chief electrical inspector in the department of public utilities, City of St. Louis.

Membership

Recommended for Transfer

The board of examiners, at its meeting on January 16, 1935, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Fairman, James F., E.E., Bklyn. Edison Co. Inc., Bklyn., N. Y.
Stryker, Clinton E., chief engr., Fansteel Products Co. Inc., No. Chicago, Ill.

2 to Grade of Fellow

To Grade of Member

Blanchard, Henry, valuation engr., The Bartlett Hayward Co., N. Y. City.
Bradfield, Charles W., engr., Duquesne Light Co., Pittsburgh, Pa.
Cook, Lee E., E.E., Texas Pwr. & Lt. Co., Dallas.
Gorton, W. V., salesman, Westinghouse E. & M. Co., Toledo, Ohio.
Gulliksen, Finn H., E.E., Westinghouse E. & M. Co., E. Pittsburgh, Pa.
Lankford, Charles H., sales engr., Century Elec. Co., St. Louis, Mo.
Love, W. S., foreman, Niagara, Lockport & Ontario Pwr. Co., Olean, N. Y.
Mettendorf, Harry A., supt., Board of Light Commissioners, Westfield, N. J.
Reisig, Carl F., supervisor of stations, Niagara Falls Pwr. Co., Niagara Falls, N. Y.
Rockwell, Edward W., engr., Metropolitan Water District of Southern Calif., Los Angeles.
Smith, Victor G., asst. prof. of E.E., Univ. of Toronto, Toronto, Ont. Canada.
Sparks, Robert, instructor in mathematics and astronomy, Hartford Public High School, Conn.
Wahl, F. S., general supt., Tonawanda Pwr. Co., No. Tonawanda, N. Y.
Work, Hans, R., lecturer of E.E., Tallinna Tehnikum, Tallinn, Estonia.

14 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before Feb. 28, 1935, or April 30, 1935, if the applicant resides outside of the United States or Canada.

Ackerlind, E., Bklyn. Poly. Inst., Bklyn., N. Y.
Anderson, F. A., Sullivan Elec. Co., Cincinnati, Ohio.
Anderson, J. R., Gen. Elec. Co., Cleveland, Ohio.
Anderson, L. D., R.C.A. Victor Co., Camden, N. J.
Andrews, D. H., 429 Oakwood Ave., E. Aurora, N. Y.
Applegate, O. E., 92 Heck Ave., Ocean Grove, N. J.
At Lee, R. Y., Am. Dist. Tel. Co., N. Y. City.
Baird, J., 402 Pine St., Boulder, Colo.
Bengel, J. E., N. Y. Central R.R., Weehawken, N. J.
Binney, J. O. (Member), Metropolitan Water Dist. of So. Calif., Los Angeles, Calif.
Bittel, H. C., Cato, N. Y.
Blade, E., John Catillon & Sons, N. Y. City.
Bonheimer, H. E., Cleveland Elec. Illum. Co., O.
Brown, J. E., Humble Oil & Refining Co., Houston, Texas.
Brown, M. T., Mohawk Mfg. Co., Detroit, Mich.
Campbell, H. A., Consolidated Aircraft Corp., Buffalo, N. Y.
Campbell, J. D., Gen. Elec. Co., Schenectady, N. Y.
Carmean, J. H., Kansas City, Mo.
Cary, S. P., Buffalo Bost Co., N. Tonawanda, N. Y.
Chapman, A. A., Chapman Elec. Co. Ltd., Yorkton, Sask., Can.
Clarke, R. B., Hilscher-Clarke Elec. Co., Canton, Ohio.
Cobine, J. D., Harvard Engg. School, Cambridge, Mass.
Collonge, P. J., Nevada Consol. Copper Co., McGill.
Compton, J. W., Rocky Gap, Va.
Condon, E. S. (Member) Maydwell & Hartzell Inc., Pasadena, Calif.
Copeland, L. W., Wadhams Oil Co., Milwaukee, Wis.
Cotter, H. G., Toledo, Ohio.
Credle, A. B., Clemson Col., Clemson College, S. C.
Currier, T. H., Natl. Lead Co., N. Y. City.

Dakan, D. L., Hope Natural Gas Co., Lumberport, W. Va.
Dalton, J. L., Reading Co., Glenside, Pa.
Daly, T. A., 45 Webb St., Hammond, Ind.
Daubenschmidt, E. R., Ward Leonard Elec. Co., Mt. Vernon, N. Y.
Diotte, N. I., Johnson Lumber Co., Cannan, N. H.
Douglas, N., Southwestern Bell Tel. Co., Kansas City, Mo.
Dynes, W. A., Natl. Park Serv., Washington, D. C.
Eck, R. N., Lake Mills, Wis.
Elkington, G.E., East Kootenay Pwr. Co., Ltd., Fernie, B. C., Can.
Ellis, C. G., Oilgear Co., Milwaukee, Wis.
Faust, D. G., Atwater Kent Mfg. Co., Philadelphia, Pa.
Fegely, H. S., 915 Poplar St., Erie, Pa.
Fleming, D. A., Oklahoma Gas & Elec. Co., Oklahoma City.
Fleming, W. W. (Member), Okonite Co., N. Y. City.
Foote, G. L., Univ. of Southern Calif., Los Angeles.
Gaudefroy, H., 4590 Hutchison St., Montreal, Que., Can.
Geiger, F. E., 178 Overlook Ave., Hackensack, N. J.
Gillespie, J. P., Tennessee Eastman Corp., Kingsport.
Glyn, R. L., Jr., Glyn's Auto Service, Topeka, Kans.
Gordon, H. L., Rhodium Corp. of Am., N. Y. City.
Grant, A. F., Winton Engine Corp., Cleveland, O.
Green, H. D. (Member), Brooklyn Edison Co., Bklyn., N. Y.
Greenberg, J. H., c/o M. R. Scharff, N. Y. City.
Griffith, G. J., General Printed String Co., Milwaukee, Wis.
Gring, M. H., Pa. Pwr. & Lt. Co., Mount Carmel, Pa.
Groo, E. R., Aerovox Corp., Brooklyn, N. Y.
Halligan, C. W., Bell Tel. Labs., N. Y. City.
Hana, T. C., Magnetic Analysis Corp., Long Island City, N. Y.
Harman, M. C., Consumers Pwr. Co., Battle Creek, Mich.
Haroldsen, E. E., Idaho Geodetic Survey, Moscow.
Hause, J., Reynolds Metals Co., Louisville, Ky.
Hebel, F., Box 186, Carpinteria, Calif.
Hibbard, B. D., Spearfish, S. D.
Hiegel, A. J., Univ. of Notre Dame, Notre Dame, Ind.
Hilford, J. V., 1405½ Massachusetts Ave., Lawrence, Kans.
Hinshaw, F. A., Bell Tel. Labs., N. Y. City.
Hoechstetter, L., c/o M. R. Scharff, N. Y. City.
Hoffmann, H. W., All Am. Cables, N. Y. City.
Hume, E. L., 69 Bellvale St., Malden, Mass.
Janes, C. W., Mich. Col. of Mining & Tech., Houghton, Mich.
Janoff, K. P., 17 Plymouth St., Johnson City, N. Y.
Jarvis, G. B., Indiana Bell Tel. Co., Indianapolis.
Jones, C. B., Union Electric Lt. & Pwr. Co., St. Louis, Mo.
Joss, E. T., Maurice Scharff, N. Y. City.
Joubert, L. P. (Member), U. S. Engineers, Portland, Ore.
Judge, J. E., Univ. of N. D., Grand Forks.
Kent, M. F., Pub. Serv. of N. J., Jersey City.
Killian, T. J., Luminous Tube Ltg. Corp., Seattle, Wash.
Kinsinger, W. W., 2128 N. 3rd St., Harrisburg, Pa.
Kluge, M. E., Broadcasting Stations KRKD & KFSG, Los Angeles, Calif.
Koch, J. W., Radio Station KFEQ, St. Joseph, Mo.
Konkel, A. A., Marion, Wis.
Koontz, R. E., National Standard Co., Niles, Mich.
Ladd, G. O., Univ. of Missouri, Columbia.
LaMothe, D. J., Michigan Coll. of Mining & Tech., Hubbell.
Lasdine, K. W., 302 Belmont, Detroit, Mich.
Leemhuis, W. J., Gen. Elec. Co., Schenectady, N. Y.
Lehmann, G. P., Iowa State Col., Ames.
Lewis, R. C. (Member), elec. & mech. engr., U. S. Navy, Brooklyn, N. Y.
Lichtman, S. W., Detrola Radio Corp., Detroit, Mich.
Linsley, S. E., Minneapolis-St. Paul Sanitary District, St. Paul, Minn.
Love, E. R., Univ. of Manitoba Fort Garry, Manitoba, Can.
McCormick, G., 4530—18th N.E., Seattle, Wash.
McDonald, B., Texas New Orleans Signal Shop, Houston, Tex.
Magowan, A. F., Elm Hill Farm, Brookfield, Mass.
Mann, A. K., Federal Pwr. Commission, Washington, D. C.
Mansur, F., 1129 E. Washington Ave., Santa Ana, Calif.
Mars, N., Purdue Memorial Union, W. Lafayette, Ind.
Marsh, D. G., 988 N. Holliston Ave., Pasadena, Calif.
Martin, T., City of Vancouver, B. C., Can.
Mathews, A. E., Dept. of Water & Pwr., City of Los Angeles, Calif.
Matthews, W. S., Jr., Union Elec. Lt. & Pwr. Co., St. Louis, Mo.
Mayes, T. L., Gen. Elec. Co., Oakland, Calif.
Merlo, C., Michigan Coll. of Mining & Tech., Laurium.
Miller, W. S., Pike Co. Agricultural Adjustment Administration, Waverly, Ohio.
Miner, R. Y., Calibron Products, Inc., West Orange, N. J.
Moore, J. K., 1083 Oak St., Salem, Ore.
Moore, R. C., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Morong, T. M., Summer St., Rowley, Mass.
Murphy, C. G., 2766 Woodhull Ave., Bronx, N. Y. City.
Navas, Y. F., N. Y. & Queens Elec. Lt. & Pwr. Co., Flushing, N. Y.
Nielsen, A. F., Exira, Iowa.
Novak, J. L., 1523 W. Superior St., Chicago, Ill.
Nutter, D. S., Shell Oil Co., Long Beach, Calif.
Oliphant, H. A., Gen. Elec. Co., Schenectady, N. Y.
Osterlund, J. A., Intl. Business Machines Corp., N. Y. City.
Park, H. F., Reese Padlock Co., Lancaster, Pa.
Peters, J., Daily News, N. Y. City.
Peterson, H. C., Univ. of Utah, Salt Lake City.
Pfeffer, W. E., Brown Instrument Co., Philadelphia, Pa.
Phillips, R. L., Montgomery Ward & Co., St. Paul, Minn.
Pollock, C., Canadian Westinghouse Co., Hamilton, Ont., Can.
Pros. J. Jr., Omaha Municipal University, Omaha, Neb.
Reimann, R., Rome Co., Long Island City, N. Y.
Reitinger, R. L., E. G. Budd Mfg. Co., Phila., Pa.
Richardson, W. M., Platte Valley Pub. Pwr. & Irrigation Dist. (Sutherland Project), North Platte, Neb.
Ringler, G. F., Narragansett Elec. Co., Providence, R. I.
Rubin, S., Forest House, 17th & Butler Sts., Easton, Pa.
Schantz, J. D., RCA Victor Co., Inc., Camden, N. J.
Schoenfeld, E., RCA Communications, Inc., Point Reyes, Calif.
Seiple, W. M., Penn. Pwr. & Lt. Co., Wilkes-Barre, Pa.
Shong, A. M., 910 N. 25th St., Milwaukee, Wis.
Shores, R. B., Gen. Elec. Co., Schenectady, N. Y.
Smith, C. B., adult education classes, Y. W. C. A., Clinton, Iowa.
Smith, D. B., Phila. Storage Battery Co., Philadelphia, Pa.
Smith, R. C., American Airlines, Inc., Fort Worth, Tex.
Smith, S. W., 31 Evergreen St., Harrisburg, Pa.
Smoyer, H. L., Tonawanda Pwr. Co., N. Tonawanda, N. Y.
Sorensen, A. D., Box 90, Coventry, R. I.
Stavros, T. H., Alabama Pwr. Co., Birmingham.
Stecker, L. H., 4030 Carpenter Ave., N. Y. City.
Stein, L. B., Jr., % Maurice R. Scharff, N. Y. City.
Stivender, P. M., Allis-Chalmers Mfg. Co., Milwaukee, Wis.
Strader, F., 217 West 95th St., N Y. C.
Stresen-Reuter, J. H., Gen. Elec. Co., Chicago, Ill.
Strojny, F. M. W., N. Y. Edison Co., N. Y. City.
Suter, W. V., Southwestern Bell Tel. Co., Little Rock, Ark.
Thiermann, A. H., Jr., Va. Elec. & Pwr. Co., Richmond.
Thompson, D. B. (Member), N. Y. C. R.R., N. Y. City.
Thompson, J. D., Centerial States Elec. Co. of Colo., Sterling.
Trull, C. E., Blackstone Valley Gas & Elec. Co., Pawtucket, R. I.
Turner, L. N., Univ. of Mich., Ann Arbor, Mich.
Ulm, L. G., Ohio Bell Tel. Co., Toledo.
Vassil, P. N., Miller Seldon Elec. & Mfg. Co., Detroit, Mich.
Voshall, R. D., Capital Transit Co., Washington, D. C.
Waite, C. E., El Monte High School, El Monte, Calif.
Warren, C. O., 525 Woodrow St., Columbus, Ohio.
Warren, R. S., Adams & Westlake Co., Elkhart, Ind.
Waters, M. V., Kelley-Koett Mfg. Co., Covington, Ky.
Westendorp, W. F., Gen. Elec. Co., Schenectady, N. Y.
Westin, L. J., Westinghouse Elec. & Mfg. Co., Allentown, Pa.
White, A. R., Square D Elec. Co., Detroit, Mich.
Wield, P. F., N. Y. Tel. Co., N. Y. City.
Williams, R. E., 227 Willowood Drive, Dayton, Ohio.
Wilson, E. S., Intl. Business Machines Corp., Endicott, N. Y.
Worden, O. L., Natl. Lead Co., Bklyn., N. Y.
Young, C. W., Jr., 91 Onderdonk Ave., Manhasset, N. Y.

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Barassi, E., "Acciaierie e Ferriere Lombarde Falck," S. I. Via, Gabrio Casati, 1, Milano, Italy.
Cunningham, A. J., Metropolitan Vickers Elec. Export Co., Rio de Janeiro, Arg., S. A.
Laycock, G., Nufsend Power Station, Sheffield, Yorks., Eng.
McEntee, E., Westinghouse Intl. Co., Santa Ana, El Salvador, Central Am.
Valls, R. P., Toro Negro Pwr. Plant, Villalba, Porto Rico.

5 Foreign

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, with the address as it now appears on the Institute record. Any member knowing of corrections to these addresses will kindly communicate them at once to the office of the secretary at 33 West 39th St., New York, N. Y.

Demeros, Andrew G., P. O. Box 787, East Pittsburgh, Pa.
Eberhard, Jacob J., 525 Grant St., Santa Clara, Calif.
Fennis, A. M., 4266 Old Orchard Ave., Montreal, Que., Can.
Fracker, Henry E., Bell Tel. Labs., 463 West St., N. Y. City.
Hansen, A. Fred, 2065½ W. 30th St., Los Angeles, Calif.
Ince, Frank Edward, 2282 Yale Ave., Maplewood, Mo.
Jordan, Arthur H., 5729 Chester Ave., Philadelphia, Pa.
Lemen, Foster M., 3009 Seward, Omaha, Nebr.
Mendez, D. P., 6 Division St., Schenectady, N. Y.
Nessler, Aldo E., Delta Starr Electric Co., 2437 W. Fulton St., Chicago, Ill.
Quinn, Robert P., Ohio Brass Co., Mansfield, Ohio.
Ryden, Eric H., Electrolux Servel Corp., 401 E. 111th St., N. Y. City.
Shirkey, Charles O., 2433 S. Crawford Ave., Chicago, Ill.
Simpson, Sidney, Deputy Loco. Supt., Eastern Bengal R. R., Kanchrapara, Bengal, India.
Skinner, Dean C., 6014 Walnut St., Pittsburgh, Pa.
Travers, James E., 12 Farwell Blk., Claremont, N. H.
Turnquist, F. A., 4 Birch Road, Wellesley, Mass.
Williams, G. M., 1331 Touhy Ave., Chicago, Ill.

18 Addresses Wanted

Engineering Literature

New Books in the Societies Library

Among the new books received at the Engineering Societies Library, New York, recently, are the following which have been selected because of their possible interest to the electrical engineer. Unless otherwise specified, books listed have been presented gratis by the publishers. The Institute assumes no responsibility for statements made in the following outlines, information for which is taken from the preface of the book in question.

A.S.T.M. STANDARDS on COAL and COKE, prepared by Committee D-5 on Coal and Coke-September 1934. Phila., American Society for Testing Materials. 108 p., illus., 9x6 in., paper, $1.00. Specifications, methods of test, and the standard definitions of terms relating to coal and coke are conveniently brought together in this publication, which includes all the material on the subject which the Society has issued. The recently approved requirements for classification of coal are also included.

A.S.T.M. STANDARDS on PETROLEUM PRODUCTS and LUBRICANTS, prepared by Committee D-2 on Petroleum Products and Lubricants, Sept. 1934. Phila., American Society for Testing Materials, 1934. 340 p., illus., 9x6 in., paper, $1.75. All the test methods, specifications, and definitions of terms referring to these materials which the Society has issued are included in this volume. In addition, there are included the reports on petroleum products and lubricants, and on gasoline. New standards are given covering fuel oils, emulsified asphalts, the gum content of gasoline, and the separation of liquid asphaltic products. Among the revisions of test methods are those for sulfur in petroleum oils, the color of lubricating oils and for emulsified asphalt.

Great Britain, Meteorological Office, Geophysical, Memoirs No. 60 (Third Number, Vol. 7). OBSERVATIONS of ATMOSPHERIC ELECTRICITY at KEW OBSERVATORY, a Survey of Results obtained from 1843 to 1931. By F. J. Scrase. London, His Majesty's Stationery Office, 1934. 27 p., illus., 12x10 in., paper, $.65 (British Library of Information, N. Y.). This report gives a brief historical sketch of the early experiments, followed by a description of the methods of observation which have been introduced more recently. The values of the potential gradient, air-earth current and positive conductivity are given.